CHAPTER SEVEN

ENVIRONMENTAL TRENDS AND THE U.S. TRANSPORTATION SYSTEM

ALTHOUGH THE ENVIRONMENTAL IMPACTS OF TRANSPORTATION CONTINUE TO BE VERY LARGE, THE UNITED STATES HAS MADE MUCH PROGRESS IN THE LAST 25 YEARS IN REDUCING SOME IMPACTS FAR BELOW WHAT THEY OTHERWISE WOULD HAVE BEEN HAD PAST TRENDS BEEN ALLOWED TO CONTINUE UNABATED. THE PROGRESS IS MOST DRAMATIC FOR AIR POLLUTANTS FROM HIGHWAY VEHICLES THAT are regulated by the federal Clean Air Act (CAA) and its amendments: the concentration of some of these pollutants in urban areas today is much less than it was in 1970, despite a doubling in vehicle-miles traveled (vmt). Much of the improvement is a result of controls on motor vehicle emissions.

Some emissions from transportation, however, have recently increased. Moreover, as is discussed in greater detail in chapter 9, the United States continues to be the world's largest producer of greenhouse gas (GHG) emissions. Transportation's share of U.S. GHG emissions has grown over the last quarter century. (Carbon dioxide (CO_2), the major GHG of concern, is an unavoidable byproduct of fossil fuel combustion.)

As travel and traffic continue to grow, it becomes increasingly important to understand and monitor the relationships between transportation and the environment

The transportation sector also has significant impacts on water quality and many other aspects of environmental quality, such as noise, alteration of habitat for plants and animals, and solid waste generation. Furthermore, transportation affects land use and shapes development patterns in complex ways. As discussed in chapter 6, measures and trend data for transportation and air pollution are far more complete than for other aspects of environmental quality.

This chapter analyzes data on transportation and the environment and discusses trends, information needs, and areas for further research. The analysis covers five areas: 1) air pollution; 2) water and groundwater contamination; 3) noise; 4) solid waste; and 5) land use and habitat modifications. Upstream activities associated with transportation, such as vehicle manufacturing, petroleum extraction and processing, construction of transportation infrastructure, and other processes needed for transportation to take place, have significant environmental impacts, but are not treated in detail here.

Air Pollution Trends

The most conspicuous environmental impact of transportation is its impact on air quality, largely due to burning and evaporation of fossil fuels. Recent and long-term trends for several kinds of air pollution are discussed in the sections that follow.

► Criteria Air Pollutants

The Clean Air Act of 1970 called for establishment of National Ambient Air Quality Standards (NAAQS) to help protect the public health and welfare from known or anticipated effects of air pollutants. (Box 8-1 in chapter 8 discusses the NAAQS.) Under the law, and its subsequent amendments, the U.S. Environmental Protection Agency (EPA) set primary and secondary ambient air quality standards for six air pollutants, known as criteria pollutants. These criteria pollutants are carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), airborne particulate matter of less than 10 microns in size (PM-10), lead, and sulfur dioxide (SO_2). The effects of these pollutants vary, but can include respiratory and cardiopulmonary problems, acid rain, decreased crop yield, defoliation of plants, and decreased visibility, as is discussed in chapter 6.

To assess national criteria pollution trends, two kinds of data are useful: 1) monitoring data about ambient concentrations of criteria pollutants in the atmosphere; and 2) estimates of total nationwide emissions from different classes of mobile and stationary pollution sources (see box 7-1.)

Monitoring data from 4,000 sites across the United States show decreases in the average concentrations of all six criteria pollutants in the 1985 through 1994 period. Decreases in ambient concentrations averaged 28 percent for CO, 12 percent for O_3, 86 percent for lead, 9 percent for NO_2, 20 percent for PM-10, and 25 percent for SO_2. (USEPA 1995a)

The national average concentrations of two criteria pollutants increased between 1993 and 1994, however. In 1994, CO concentrations increased 2 percent and the composite average for NO_2 increased 5 percent over 1993 levels. (Lead and sulfur dioxide concentrations continued to decrease, while PM-10 concentrations did not change.) Furthermore, over 62 million people still lived in counties that had not attained or met the NAAQS for at least one criteria pollutant in 1994. Clearly, pollution problems remain. (USEPA 1995a)

Transportation vehicles are major sources of several criteria emissions. They account for most emissions from mobile sources, which include road vehicles and a diverse mix of mobile nonroad sources and equipment (see box 7-2). In 1994, mobile sources (including both road and nonroad sources) accounted for 78 percent of all

Box 7-1: Measuring Air Quality and Vehicle Emissions Trends

The U.S. Environmental Protection Agency (EPA) monitors ambient air quality trends at 4,000 sites nationwide. Numerous samples are collected at each site throughout the year. Not all pollutants are measured at a site and different air quality indicators are used to characterize each pollutant to determine compliance with air quality standards aimed at protecting public health. The carbon monoxide standard specifies one-hour and eight-hour concentration levels; for an area to attain the standard, these averages could be exceeded only once a year. The ozone standard specifies a maximum daily one-hour average concentration to be met or bettered every day of the year. The lead standard is a maximum quarterly average. The nitrogen dioxide standard is an annual arithmetic mean. For PM-10 and sulfur dioxide, the standards specify average concentrations for the short term (24 hours or less) and long term (annual average).

EPA ranks each pollutant by the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. The arithmetic average for all sites is reported. Arithmetic averages are reported for sites categorized by location as rural, urban, and suburban. Finally, the areas failing to meet at least one pollutant standard are listed together with an indication of which standards were not attained. These measures do not fully describe the air quality of the United States or even that of a particular site. With so many sites and observations around the country, however, they give a useful indication of national air quality trends.

EPA also prepares annual nationwide estimates of emissions of key pollutants from stationary and mobile sources. Mobile sources include eight categories of on-road vehicles and major categories of nonroad transportation vehicles (e.g., aircraft, boats, and locomotives), and mobile equipment such as lawnmowers and construction equipment. To estimate emissions from on-road vehicles, EPA makes use of several kinds of data, such as Federal Highway Administration data on vehicle-miles traveled, state-level temperature data, and data from the Federal Test Procedure (FTP), which also is used to certify compliance of newly manufactured vehicles with federal emissions standards. Emissions estimates have been prepared for every year from 1970 through the present. EPA sometimes revises its prior estimates of emissions as understanding and information about factors affecting emissions grows. Recent research suggests that emissions estimates based on FTP assumptions have underestimated real-world emissions. This issue is discussed in detail in box 8-2 in chapter 8.

SOURCES: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1994*, EPA 454/R-95-014 (Research Triangle Park, NC: October 1995); and U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995).

CO emissions, 45 percent of all nitrogen oxides NO_x emissions, and 37 percent of all hydrocarbon (HC) or volatile organic compounds (VOC) emissions. The latter three classes of substances contribute to the formation of ground-level ozone, another criteria pollutant present in smog (see figure 7-1). Although mobile sources still accounted for 32 percent of 1994 lead emissions, vehicular lead emissions are now less than 1 percent of their 1970 levels because lead has been eliminated from motor gasoline. Mobile sources account for less than 3 percent of SO_2 emissions.

Highway vehicle travel accounts for most criteria pollution from the transportation sector. On-road vehicles produced 62 percent of all CO emissions, 32 percent of all NO_x emissions, and 26 percent of all VOC emissions in 1994. Between 1970 and 1994, the highway vehicle fleet grew 80 percent, and annual vehicle-miles traveled nationwide doubled. (USDOT BTS 1995, table 5, 33, 41) Technological changes resulting from the CAA, however, have controlled highway vehicle emissions to a substantial degree (see figure 7-2). In part because of the control of

Box 7-2: Transportation's Share of Mobile Source Pollution

The U.S. Environmental Protection Agency (EPA) divides air pollution sources into stationary sources and mobile sources. Mobile sources are further divided into on-road sources and nonroad sources. EPA prepares emissions estimates each year for the following mobile sources:

On-road mobile sources:
- Light-duty gas vehicles and motorcycles
- Light-duty gas trucks
- Heavy-duty gas vehicles
- Light-duty diesel vehicles
- Light-duty diesel trucks
- Heavy-duty diesel trucks

Nonroad mobile sources:
- Aircraft
- Marine vessels (includes estimates for coal, diesel, and residual oil)
- Railroads
- Other nonroad gasoline and diesel sources, including:
  - recreation
  - construction
  - industrial
  - lawn and garden
  - farm
  - light commercial
  - logging
  - airport service
  - recreational marine vessels (gasoline only)
  - other (gasoline only)

All emissions from on-road sources, aircraft, marine vessels, and railroads can be attributed to transportation. Some other nonroad emissions (such as from airport services and recreational marine vessels) also are transportation-related. Emissions from some nonroad sources (such as lawn and garden equipment) clearly should not be attributed to transportation, and, strictly speaking, only a portion of the emissions from nonroad mobile equipment used in industry, construction, and farming should be attributed to transportation, since the equipment may also be used to process goods and materials.

On-road sources (especially light-duty gasoline vehicles, which have been subject to the most stringent emissions standards) account for most of the progress in reducing emissions from mobile sources over the years. Overall emissions from less regulated mobile sources (both in the on-road and nonroad categories) have increased for some pollutants.

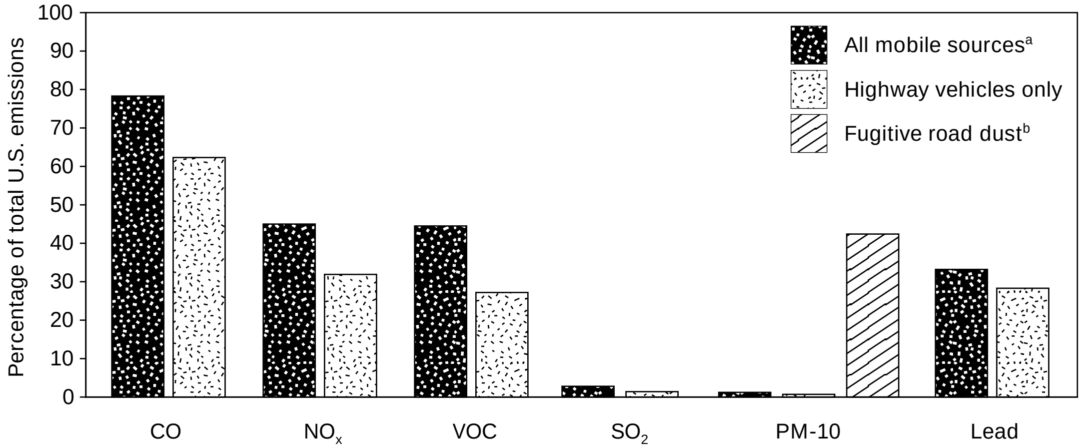
A life-cycle accounting of air pollution from the transportation sector also would need to take into account the fraction of emissions from stationary sources that produce, store, or dispose of raw materials and goods used in transportation. Examples include oil wells, petroleum refineries and storage facilities, and factories for manufacture of materials, parts, and vehicles used for transportation.

road vehicle emissions, the concentration of criteria pollutants in the air has decreased, and ambient air quality is better in most areas (see figure 7-3).

Most of the progress to date in curbing criteria air pollution from transportation can be attributed to: 1) tailpipe or other emissions standards for newly manufactured highway vehicles (see table 7-1 for examples); and 2) requirements that harmful substances be reduced or removed from fuels, or that substances be added to fuels to make them pollute less. (Thus, lead essentially has been eliminated from fuel, and the sulfur content of fuel has been reduced greatly).

As is reported later in this chapter, had nothing been done, tailpipe and other vehicular emissions of criteria pollutants would have more than doubled between 1970 and 1994 because of the growth in travel. Instead, EPA estimates that

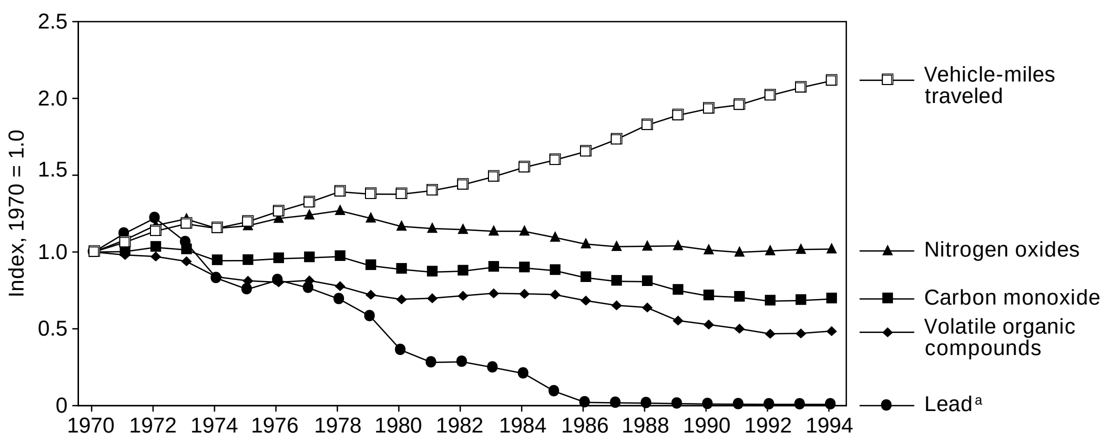
FIGURE 7-1: TRANSPORTATION'S SHARE OF U.S. CRITERIA POLLUTANT EMISSIONS, 1994



[a] "All mobile sources" include highway vehicles, nonroad vehicles, and mobile equipment, some of which may be used in nontransportation applications such as lawn and garden care.
[b] Fugitive road dust is particulate emissions kicked up from paved and unpaved roads. EPA lists road dust as a miscellaneous source of PM-10, not as a mobile source.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1900–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), tables A1–A6.

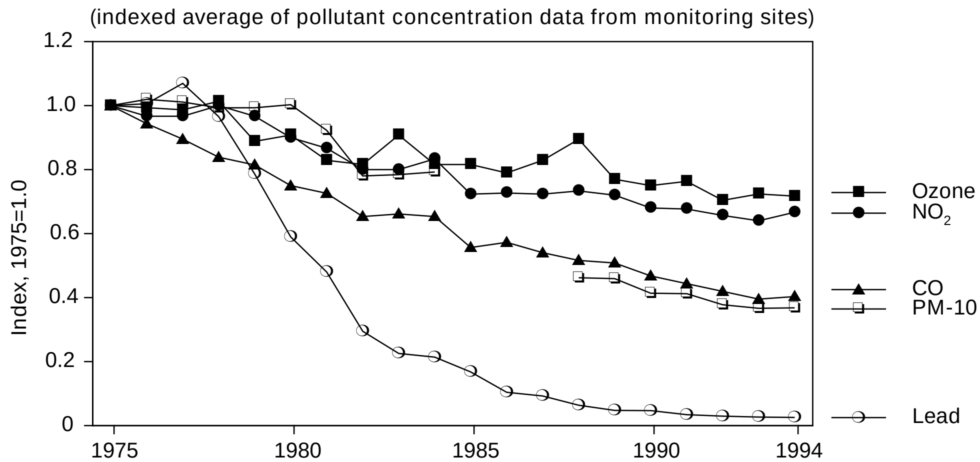
FIGURE 7-2: ROAD VEHICLE AIR EMISSIONS AND MILES TRAVELED, 1970–94



[a]Lead emissions since 1990 have been less than 1 percent of their 1970 levels.

SOURCES: Vehicle-miles—U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: various years). Emissions—U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994* (Washington, DC: 1995), tables A-1, A-2, A-3.

FIGURE 7-3: U.S. AIR QUALITY TRENDS, 1975–94



SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1994, Data Appendix,* EPA 454/R-95-XXX (Research Triangle Park, NC: October 1995), table A-9.

TABLE 7-1: FEDERAL EMISSIONS CONTROL STANDARDS FOR LIGHT-DUTY GASOLINE VEHICLES (GRAMS PER MILE)

	Automobiles				Light trucks			
Year standard set or changed	**Hydro-carbons**	**Carbon monoxide**	**Nitrogen oxides**	**Particulates**	**Hydro-carbons**	**Carbon monoxide**	**Nitrogen oxides**	**Particulates**
1976	1.50	15.0	3.1	—	2.00	20.0	3.1	—
1977	nc	nc	2.0	—	nc	nc	nc	—
1979	nc	nc	nc	—	1.70	18.0	2.3	—
1980	0.41	7.0	nc	—	nc	nc	nc	—
1981	nc	3.4	1.0	—	nc	nc	nc	—
1982	nc	nc	nc	0.60	nc	nc	nc	0.60
1984	nc	nc	nc	nc	0.80	10.0	nc	nc
1987	nc	nc	nc	0.20	nc	nc	nc	0.26
1988	nc	nc	nc	nc	nc	nc	1.2	nc
1994	0.25	nc	0.4	0.08	0.25	3.4	nc	nc
1995 on	nc	nc	nc	nc	nc	nc	0.4	0.08

KEY: — = no emission standard in effect; nc = no change from prior year listed.

SOURCE: S.C. Davis, *Transportation Energy Data Book, Edition 15*, ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 7-14.

highway vehicles emit only half the VOC and 30 percent of the CO as in 1970; motor vehicle emissions of NO_X are higher but by only 2 percent (USEPA 1995b, tables 3-1, 3-2, 3-3). As a result, concentrations of these air pollutants in the atmosphere generally are lower today despite continuing growth in vehicle travel.

Yet, the most recent data on emissions suggest a slowing of the improvements that characterized the past two decades. Steady growth in travel coupled with increased emissions from previously unregulated off-highway sources may overtake the impressive emissions reductions achieved under past standards. Since 1991, for example, NO_X emissions from mobile sources increased 4.5 percent; about one-third of the increase is attributed to on-road vehicles, the remainder to nonroad mobile sources (including nontransportation sources such as lawnmowers as well as marine, air, and rail transportation vehicles). (USEPA 1995b, table A-2)

Tightened emissions standards for new cars and light-duty trucks, as well as requirements for cleaner burning oxygenated and reformulated fuels, were put in place in 1994 and 1995, as called for in the 1990 Clean Air Act Amendments (CAAA) (see table 7-1). New standards for heavy-duty trucks, buses, other transportation modes, and some categories of off-road vehicles and equipment are scheduled to be promulgated in the coming years. Moreover, as is discussed in chapter 8, enhanced inspection and maintenance (I/M) programs, and transportation control measures are in place or under consideration in many metropolitan areas with air quality problems. These initiatives will help to ameliorate air quality impacts from future growth in stationary and mobile source emissions, although perhaps not enough to prevent overall growth in emissions (see chapter 8).

In the long term, technological advances could further reduce criteria emissions. The federal government and some states have sponsored or cost-shared with industry research on cleaner engine technologies, alternative fuels, and advanced emissions control devices. (US Congress OTA 1995a) In time, such research could lead to new vehicles or fuels that are less polluting.

Carbon Monoxide

Highway vehicles accounted for almost 80 percent of the CO emitted from mobile sources in 1994 (table 7-2). (Gasoline vehicles accounted for almost all the highway vehicle emissions—diesel-powered vehicles accounted for only a little over 2 percent.) CO emissions from highway vehicles decreased by 21 percent in the 1985 to 1994 period in spite of the increase in vmt. Much of the decrease is the result of improved engine designs that burn fuel at near-optimum air-fuel ratios and the use of catalytic converters that oxidize most of the CO in engine exhaust to produce CO_2.

Between 1992 and 1994, CO emissions from highway vehicles increased by about 2 percent, however. Many factors will affect the level of highway vehicle emissions in the future. A more stringent CO emissions standard for new light-duty trucks was put in place in 1994. Additional emissions reductions may occur if more areas adopt reformulated and oxygenated fuel programs called for by the 1990 Clean Air Act Amendments. Oxygenated fuel programs are mandated in CO nonattainment areas and can also be implemented on a voluntary basis in areas that are within attainment standards. These and other measures will help offset emissions from growth in travel and other sources—although to what degree remains to be seen.

Nonroad sources contributed over 20 percent of all CO emissions from mobile sources in 1994, up from 15 percent in 1985. (USEPA 1995b, table A-1) Off-highway vehicles with gasoline engines accounted for most of the growth; emissions from these sources increased 14 percent between 1985 and 1994. The category includes a mixture of transportation and non-

TABLE 7-2: CARBON MONOXIDE EMISSIONS BY SOURCE, 1985, 1992, AND 1994
(THOUSAND SHORT TONS)

Source category	1985	1992	1994	Percentage change 1985–94	Percentage change 1992–94
Mobile sources	91,093	74,758	76,727	–15.8	2.6
Highway vehicles	77,387	59,859	61,070	–21.1	2.0
Light-duty gas vehicles and motorcycles	49,451	39,370	39,303	–20.5	–0.2
Light-duty gas trucks	18,960	14,567	15,140	–20.1	3.9
Heavy-duty gas vehicles	7,716	4,569	5,244	–32.0	14.8
Diesels	1,261	1,352	1,384	9.8	2.4
Nonroad vehicles and mobile equipment	13,706	14,900	15,657	14.2	5.1
Nonroad gasoline[a]	11,815	12,883	13,452	13.9	4.4
Nonroad diesel[a]	910	853	954	4.8	11.8
Aircraft	831	980	1,063	27.9	8.5
Marine vessels	44	60	63	43.2	5.0
Railroad	106	124	124	17.0	0.0
Fuel combustion	8,487	5,601	4,884	–42.5	–12.8
Industrial processes	7,216	6,911	7,161	–0.8	3.6
Miscellaneous	7,895	6,774	9,245	17.1	36.5
Total emissions	114,690	94,043	98,017	–14.5	4.2

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from lawn and garden equipment, a nontransportation source, accounted for 40 percent of nonroad mobile source carbon monoxide and 8 percent of all mobile source carbon monoxide emissions.

NOTE: Subtotals may not add due to rounding. Data for 1992 included because carbon monoxide emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-1, pp. A2–A5.

transportation sources, including recreational boats, off-road commercial vehicles, and lawn and garden equipment. The 1990 CAAA established emissions standards for nonroad vehicles and equipment. In 1996, these standards will be applied to new equipment. Thus it will be several years before significant effects on nonroad emissions will be apparent.

Urban Ozone

Ground-level ozone, the major constituent of smog, is formed by photochemical reactions involving sunlight, NO_X, and volatile organic compounds. Urban ozone formation is highly dependent on meteorological conditions, peaking during hot, dry, stagnant summertime weather. Since weather conditions vary, sometimes greatly, from year to year, so too does the formation of O_3. Estimates that account for meteorological variation have found that the O_3 concentration decreased by about 12 percent between 1985 and 1994. The number of O_3 nonattainment areas dropped from 94 in September 1993 to 77 in September 1994. (USEPA 1994, USEPA 1995a)

Mobile sources accounted for nearly 37 percent of all VOC emissions in 1994 (see table

7-3). VOC emissions from mobile sources declined by nearly 25 percent between 1985 and 1994; however, 1994 emissions exceeded those in 1992 (the low point) by 3.9 percent. Of the mobile source emissions, highway vehicles accounted for 73.6 percent, and nonroad gasoline vehicles were responsible for 20.2 percent.

Several measures could further reduce VOC emissions from highway vehicles. These include enhancing or expanding I/M programs, reducing the vapor pressure of gasoline to decrease evaporative emissions, increasing use of oxygenated fuel for more complete combustion, and tightening of tailpipe emission standards.

Nonroad mobile sources of VOC emissions increased by 12.3 percent from 1985 to 1994. Roughly one-third of these nonroad emissions came from a nontransportation use (lawn and garden equipment). Recreational boats were the next largest source, accounting for one-fifth of nonroad VOC emissions from mobile sources.

Upstream emissions of VOCs from the production, refining, transport, storage, and handling of transportation fuels and other petroleum products are substantial. Petroleum production and refining produced 630,000 short-tons of VOCs in 1994, while storage and transport, including service stations, generated 1,773,000

TABLE 7-3: VOLATILE ORGANIC COMPOUNDS EMISSIONS BY SOURCE, 1985, 1992, AND 1994 (THOUSAND SHORT TONS)

Source category	1985	1992	1994	Percentage change 1985–94	Percentage change 1992–94
Mobile sources	11,384	8,231	8,550	–24.9	3.9
Highway vehicles	9,376	6,072	6,295	–32.9	3.7
Light-duty gas vehicles and motorcycles	5,864	3,832	3,921	–33.1	2.3
Light-duty gas trucks	2,425	1,588	1,664	–31.4	4.8
Heavy-duty gas vehicles	716	334	393	–45.1	17.7
Diesels	370	318	317	–14.3	–0.3
Nonroad vehicles and mobile equipment	2,008	2,159	2,255	12.3	4.4
Nonroad gasoline[a]	1,561	1,677	1,730	10.8	3.2
Nonroad diesel[a]	216	203	226	4.6	11.3
Aircraft	165	195	212	28.5	8.7
Marine vessels	30	41	43	43.3	4.9
Railroad	37	43	43	16.2	0.0
Fuel combustion	1,569	1,023	886	–43.5	–13.4
Industrial processes	12,283	12,703	13,054	6.3	2.8
Miscellaneous	562	466	685	21.9	47.0
Total emissions	25,798	22,420	23,174	–10.2	3.3

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from lawn and garden equipment, a nontransportation source, accounted for 9 percent of all mobile source volatile organic compounds emissions.

NOTE: Subtotals may not add due to rounding. Data for 1992 included because volatile organic compounds emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-3, pp. A10–A16.

short-tons. If included in the transportation sector, these upstream activities would add 28 percent more VOC emissions to the mobile source totals for 1994.

Nitrogen Oxides

Nitrogen dioxide is a criteria pollutant; therefore, EPA measures NO_2 concentrations in the ambient atmosphere. NO_2 concentrations across the United States decreased an average of 9 percent from 1985 to 1994. From 1993 to 1994, however, NO_2 concentrations increased by 5 percent. (USEPA 1995a) Even so, all monitoring stations in the country met the NO_2 emissions standard in 1994 for the third year in a row. (USEPA 1995a) Control of NO_2 emissions are important for reducing levels of O_3, which exceed NAAQS in many areas.

Tailpipe and other emissions standards have been set for all forms of nitrogen oxides, which include several substances that quickly turn into NO_2 or can themselves contribute to the formation of smog. In 1994, according to EPA, electric utilities and industry accounted for about half of the NO_x emissions; mobile sources accounted for 45 percent. Highway vehicles accounted for 71 percent of mobile source NO_x emissions in 1994 (see table 7-4).

NO_x emissions from on-road vehicles declined by 6.9 percent between 1985 and 1994, while emissions from off-highway vehicles increased by 13.2 percent in the same period. Since 1991, however, NO_x emissions from both highway and nonroad vehicles increased, with highway vehicle emissions increasing by about 2.1 percent. (USEPA 1995a)

Diesel engines have high compression ratios, and therefore produce proportionately more NO_x than gasoline engines. Emissions from diesel-powered vehicles, both road and nonroad (including railroad and marine diesels), account for 45 percent of mobile source NO_x emissions—a much higher share than their modest percentage of the vehicle population and vmt. Emissions from diesel-powered highway vehicles decreased by 17 percent between 1985 and 1994. Railroad diesels contributed 9 percent to the mobile source total in 1994, increasing by 17 percent since 1985. Marine diesels contributed 1.8 percent to the mobile source total in 1994, increasing by nearly 44 percent since 1985. Other off-highway diesel emissions increased by 7 percent over the same period. (USEPA 1995a) Some of the off-highway diesel emissions come from construction equipment used to build or maintain transportation infrastructure.

Lead

At one time, transportation vehicles were the primary source of lead emissions in the United States, contributing about four-fifths of total lead emissions as recently as 1985. Air pollution control programs implemented by EPA, however, have nearly eliminated lead emissions from transportation fuels. Unleaded gasoline, introduced in 1975 to prevent fouling of catalytic exhaust emissions control devices, accounted for 99 percent of gasoline sales by 1993.

Although transportation still contributes 32 percent of total lead emissions, the base is much smaller (see figure 7-4 and table 7-5). Currently, 10 areas exceed the NAAQS for lead—mostly due to point sources such as lead smelters, battery plants, and solid waste disposal. (USEPA 1995a). Some of these facilities provide products or disposal services to the transportation sector.

Particulate Matter

In 1994, more areas were classified as nonattainment for PM-10 than for any other criteria pollutant. The number of nonattainment areas increased from 70 in 1991 to 82 in 1994. (USEPA 1994, USEPA 1995a) (PM-10 concentrations have been separately measured since

TABLE 7-4: NITROGEN OXIDES EMISSIONS BY SOURCE, 1985, 1991, AND 1994
(THOUSAND SHORT TONS)

Source category	1985	1991	1994	Percentage change 1985–94	Percentage change 1991–94
Mobile sources	10,823	10,170	10,625	–1.8	4.5
Highway vehicles	8,089	7,373	7,530	–6.9	2.1
Light-duty gas vehicles and motorcycles	3,806	3,464	3,750	–1.5	8.3
Light-duty gas trucks	1,530	1,339	1,432	–6.4	6.9
Heavy-duty gas vehicles	330	326	333	0.9	2.1
Diesels	2,423	2,244	2,015	–16.8	–10.2
Nonroad vehicles and mobile equipment	2,734	2,796	3,095	13.2	10.6
Nonroad gasoline[a]	113	122	133	17.7	9.0
Nonroad diesel[a]	1,562	1,433	1,673	7.1	16.7
Aircraft	119	139	153	28.6	10.1
Marine vessels	131	174	188	43.5	8.0
Railroad	808	929	947	17.2	1.9
Fuel combustion	10,837	11,382	11,728	8.2	3.0
Industrial processes	891	837	889	–0.2	6.2
Miscellaneous	309	283	374	21	32.2
Total emissions	22,860	22,672	23,615	3.3	4.2

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from nonroad construction vehicles and mobile equipment accounted for 14 percent of all mobile source nitrogen oxides emissions.

NOTE: Subtotals may not add due to rounding. Data for 1991 included because nitrogen oxides emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-2, pp. A6–A9.

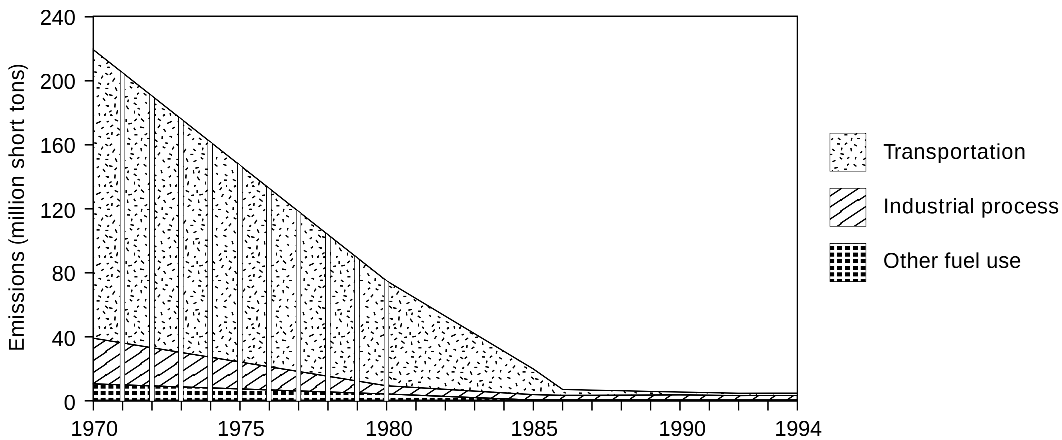
1988; before 1988, PM-10 was not distinguished from larger suspended particulates.)

PM-10 sources include both anthropogenic and natural sources. Most PM-10 originates from diffuse sources that cover large areas (e.g., dust from roads and farms, from fires, and wind erosion). These “miscellaneous” and “natural” sources account for the lion’s share—94 percent—of PM-10 emissions. The remaining PM-10 emanates from discrete or point sources (e.g., transportation vehicles, manufacturing, and other industrial processes).

Of this small share of PM-10 from discrete anthropogenic sources, transportation vehicles contributed 27 percent in 1994. Since 1988, PM-10 emissions from highway vehicles decreased, while emissions from off-highway vehicles increased. Nonhighway diesels, in particular, accounted for one-third of the vehicular PM-10 emissions.

Fugitive road dust—dust kicked up from paved and unpaved roads—is categorized as a miscellaneous, not as a transportation source of PM-10. From 1985 to 1994, dust from paved roads increased by 25 percent, while dust from unpaved roads increased by 11 percent. In 1994, according to EPA, road dust accounted for over 40 percent of all anthropogenic and biogenic

FIGURE 7-4: LEAD EMISSIONS BY SOURCE IN THE UNITED STATES, 1970–94



NOTE: Data between 1970 and 1980 are interpolated.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollution Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-6, pp. A26–A27.

TABLE 7-5: LEAD EMISSIONS BY SOURCE, 1985 AND 1994 (SHORT TONS)

Source category	1985	1994	Percentage change 1985–94
Mobile sources	16,207	1,596	–90.2
Highway vehicles	15,978	1,403	–91.2
Light-duty gas vehicles and motorcycles	12,070	1,048	–91.3
Light-duty gas trucks	3,595	336	–90.7
Heavy-duty gas vehicles	313	19	–93.9
Nonroad mobile sources	229	193	–15.7
Fuel combustion	515	493	–4.3
Industrial processes	3,402	2,868	–15.7
Total emissions	20,124	4,956	–75.4

NOTE: Subtotals may not add due to rounding.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-6, pp. A26–A27.

PM-10 emissions. (USEPA 1995b) Road dust also accounted for over 30 percent of emissions of very fine particles—those measuring 2.5 microns or smaller (PM-2.5). (Barnard 1996)

A debate exists about what size and kind of road dust should be used in setting health-based attainment standards for particulate matter. Further research into the relationships between health effects and particle size and composition will be needed to clarify and eventually quantify the specific health effects of road dust particulate pollution.

Sulfur Dioxide

In 1994, 43 areas were classified as nonattainment for sulfur dioxide (SO_2), mostly due to emissions from electric utilities and industrial point sources. (USEPA 1995a) The U.S. transportation sector contributed very little to SO_2 emissions since the demise of the coal-fired locomotive. In 1994, transportation accounted for only 2.7 percent of the nation's total SO_2 emissions—a substantial drop from 1993, when new CAAA regulations required a reduction in the sulfur content of diesel fuel for highway vehicles. Even so, highway vehicles still accounted for half of transportation's SO_2 emissions in 1994. Sulfur oxides from other transportation sources, including marine transport, locomotives, and aircraft, increased between 1985 and 1994.

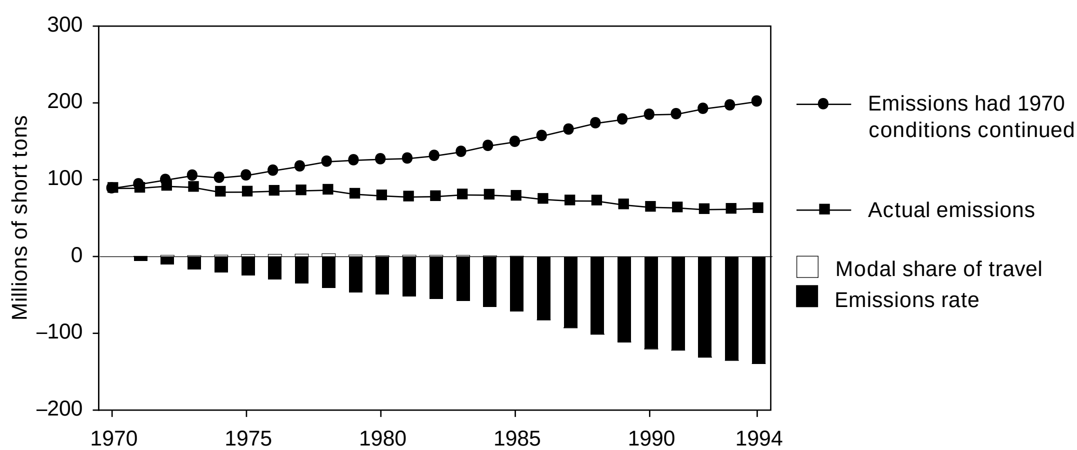
Long-Term Trends in Criteria Emissions

The Bureau of Transportation Statistics (BTS) has applied Divisia Analysis (discussed in chapter 4) to show how rates of emissions per vehicle-mile and changes in modal structure (distribution of travel across modes) affected transportation emissions between 1970 and 1994. The analysis focuses on emissions of three key criteria pollutants—CO, VOC (or HC), and NO_x. Two conclusions emerge from the analysis: 1) without the reductions in emissions rates since 1970, air pollution by transportation would be two to four times what it is today; 2) changes in the modal structure of transportation had virtually nothing to do with this result. (See figures 7-5, 7-6, 7-7).

The analysis makes use of EPA emissions data for six categories (modes) of transportation vehicles: 1) passenger cars and motorcycles, 2) light trucks, 3) heavy-duty highway vehicles, 4) aircraft, 5) railroad vehicles, and 6) marine vessels (not including recreational boats). These categories account for between 70 and 80 percent of all mobile source emissions of the three pollutants, and an even higher proportion of transportation activity. They also are the categories for which adequate travel activity data are available. Activity for highway vehicles is measured in vehicle-miles. Commercial air activity is measured in aircraft-miles for domestic and international flights by U.S. certificated air carriers. Rail is measured by freight car-miles, and marine vessel activity by total tons shipped in domestic and international waterborne commerce. (German 1995)

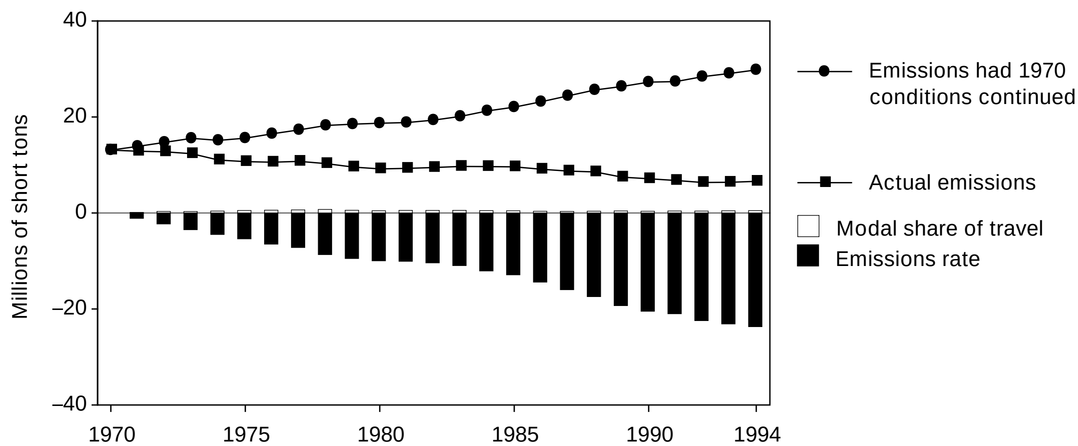
Over the 1970 to 1994 period, actual emissions from these six transportation categories declined significantly in the cases of CO and VOC and increased only slightly in the case of NO_x. During this time period, transportation activity doubled. The Divisia Analysis shows

FIGURE 7-5: CARBON MONOXIDE EMISSIONS FROM U.S. TRANSPORTATION, 1970–94



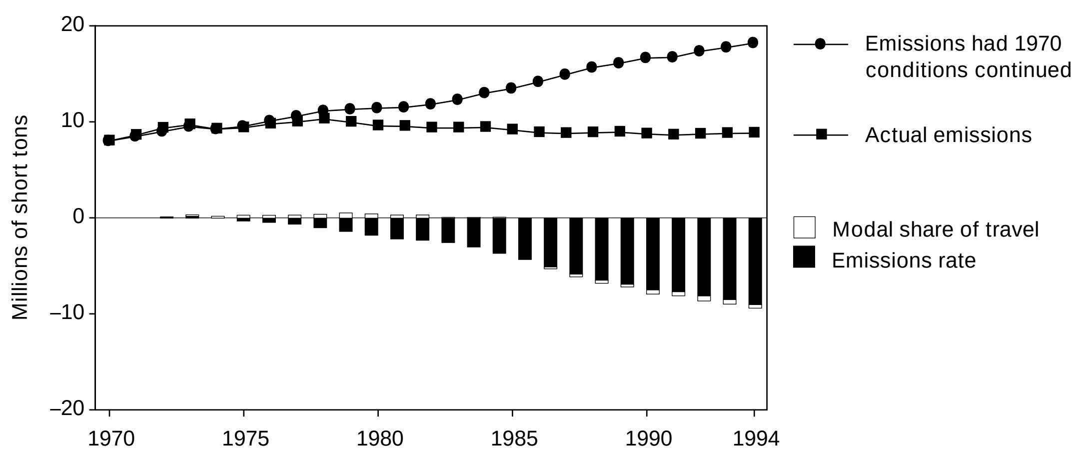
SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

FIGURE 7-6: VOLATILE ORGANIC COMPOUNDS EMISSIONS FROM U.S. TRANSPORTATION, 1970–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

FIGURE 7-7: NITROGEN OXIDES EMISSIONS FROM U.S. TRANSPORTATION, 1970–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

that without the improvement, VOC emissions from transportation would be 4.5 times what they are today, CO emissions 3.2 times as great, and NO_x emissions 2 times as great.

The improvement in transportation emissions has kept overall U.S. emissions from all sources at a lower level than would otherwise have been the case. For example, the six modes of transportation account for 64 percent of CO emissions from all sources. Without the improvement in transportation emissions, *total* emissions of CO would have been 2.4 times their actual level in 1994. Total VOC emissions, of which these six categories of transportation accounted for 28 percent in 1994, would have been twice as great.

Even total NO_x emissions, of which these six transportation modes accounted for 37 percent in 1994, would have been 40 percent greater had there been no improvements in transportation emissions rates.

As shown in figure 7-7, the improved trend for NO_x emissions did not begin in earnest until about 1980. This marks the beginning of widespread use of three-way catalytic converters in automobiles, which are capable of reducing NO_x as well as oxidizing HC and CO, the tightening of NO_x standards for light trucks in 1979, and the introduction of heavy-duty vehicle standards in 1984.

► Toxic Air Pollutants

The 1990 CAAA placed renewed emphasis on regulation of toxic air pollutants (substances known or thought to cause cancer or other serious illness). Although it is clear that vehicles and fuels are major sources of certain toxic pollutants, comprehensive data are not yet available. EPA's Toxic Release Inventory, covering about 600 chemicals, applies to manufacturing facilities and provides little information about transportation emissions. Other national inventories for specific pollutants are under preparation to support studies called for by the 1990 CAAA. These inventories do not cover all toxics, and the collection methods vary. EPA is developing a more comprehensive toxics database which is expected to be available in 1996.

Fuels used by internal combustion engines are the principal sources of the key hazardous air pollutants (HAPs)—benzene, 1,3-butadiene, and formaldehyde—according to EPA estimates. (USEPA 1995b, tables 8-2, 8-3, 8-4) Onroad mobile sources accounted for 45 percent of EPA's estimated benzene emissions, 38 percent of 1,3-butadiene, and 37 percent of formaldehyde. If all nonroad mobile sources were counted as well, the mobile source share would rise to 64 percent of benzene, 79 percent of 1,3-butadiene, and 53 percent of formaldehyde. (This total includes nontransportation sources such as lawnmowers and construction equipment.) Upstream emissions during the production of petroleum fuels are also a source of benzene emissions (4 percent).

Marine vessel loading and unloading operations also can be sources of toxic air emissions, because vapors are released into the air when liquids are loaded into or removed from cargo holds. Such operations may release as many as 60 of the 189 HAPs listed in Title III of the 1990 CAAA, including benzene, toluene, ethylbenzene, and xylenes (BTEX). BTEX emissions have been shown to contribute to cancer, liver and kidney damage, and neurological and developmental effects. In 1990, the total emissions of HAPs from marine vessel loading totaled about 8,800 short tons, less than 1 percent of the total toxic emissions reported by EPA for that year. EPA has proposed regulations that would reduce emissions to about 400 short tons annually. (USEPA 1995b)

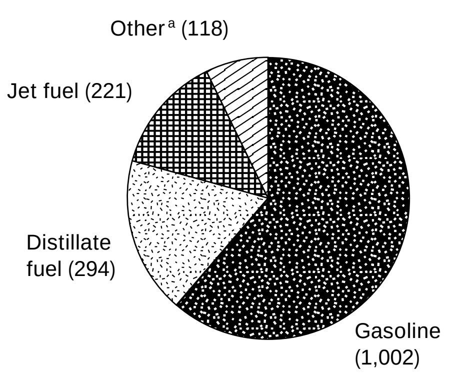
► Greenhouse Gas Emissions

CO_2 is the predominant greenhouse gas released from anthropogenic sources, accounting for about 85 percent of the total emissions, weighted by global warming potential. Methane, nitrous oxides, and other less common gases account for 15 percent of the total global warming potential of greenhouse gases.

Of the 5.12 billion metric tons of CO_2 released from fossil fuel combustion in 1994, transportation was responsible for more than 1.6 billion metric tons (see figure 7-8). While the transportation sector's annual share of these emissions has remained at about 32 percent each year from 1987 to 1994, the actual emissions from transportation increased by 8.6 percent over this period, in line with the 8.9 percent increase for total emissions (see figure 7-9).

Carbon dioxide accounted for all but 3 percent of transportation's 1993 GHG emissions.

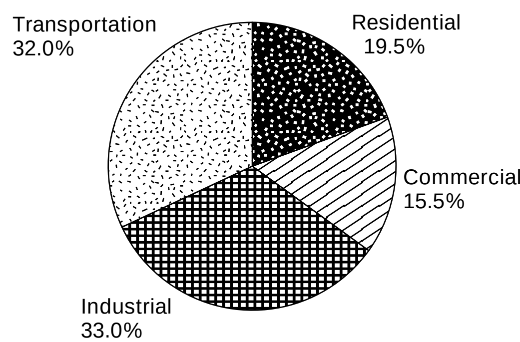
FIGURE 7-8: CARBON DIOXIDE EMISSIONS FROM THE U.S. TRANSPORTATION SECTOR, 1994 (MILLION METRIC TONS)



[a] These are, in descending order, residual fuel oil (70); natural gas (34); lubricants, liquefied petroleum gas, etc. (10); and electricity (2).

SOURCE: U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987–1994*, DOE/EIA-0573 (87–94) (Washington, DC: 1995), table C-4.

FIGURE 7-9: CARBON DIOXIDE EMISSIONS IN THE UNITED STATES, 1994



SOURCE: U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987–1994*, DOE/EIA-0573 (87-94) (Washington, DC: October 1995), table 5.

(USDOE 1995c) Combustion of petroleum fuels accounted for nearly 98 percent of transportation's CO_2 emissions; gasoline contributed more than 60 percent of the CO_2 from transportation. (USDOE 1995d, table C-4, 92)

Despite significant energy efficiency improvements, transportation activity outpaced efficiency gains, resulting in increased energy use and increased CO_2 emissions. Total transportation energy use increased from 19.7 quadrillion Btu in 1980 to 23.5 quadrillion Btu in 1994. (USDOE 1995c, table 2-1) Transportation emissions of carbon dioxide grew accordingly from 379 million metric tons to 446 million metric tons of carbon. (One ton of carbon equals 3.667 tons of CO_2.)

According to U.S. Department of Energy projections, CO_2 emissions by transportation could increase by 1.3 percent per year through 2010, despite greater use of alternative fuels. (USDOE 1995a) As discussed in chapter 4, gains in energy efficiency have slowed, while vehicle travel continues to grow. Moreover, despite the interest in alternative fuels, petroleum is expected to remain the dominant transportation fuel through at least 2010. Furthermore, most alternative fuels are derived from natural gas or natural gas byproducts. While natural gas and natural gas-based fuels reduce CO_2 emissions relative to petroleum-based fuels, they do not eliminate them. In addition, energy use in upstream processing of alternative fuels reduces their greenhouse gas advantage (see table 7-6). Even battery-powered electric vehicles provide little or no benefit if the electricity is generated from fossil fuels, as is now the case for most U.S. electricity. Unless a widespread switch occurs to cellulosic ethanol (made from woody plants), other renewable-based fuel sources, solar, or nuclear power, even large market penetrations of alternative fuels could have little effect on transportation greenhouse gas emissions.

TABLE 7-6: CARBON DIOXIDE-EQUIVALENT EMISSIONS OF ALTERNATIVE FUELS: LIGHT-DUTY VEHICLES (GRAMS PER MILE)

Fuel/vehicle	Vehicle use	Upstream emissions	Total emissions
Conventional gasoline	344.5	85.9	430.4
Reformulated gasoline	333.7	101.6	435.3
Diesel fuel	325.0	56.8	381.8
Methanol from natural gas	277.4	151.5	428.9
Methanol from coal	277.4	464.7	742.1
Methanol from cellulose	51.4	97.4	148.8
Compressed natural gas	269.0	91.9	360.9
Compressed natural gas from cellulose	64.4	130.2	194.6
Liquid petroleum gas	283.6	36.9	320.5
Ethanol from corn	51.0	481.2	532.2
Ethanol from cellulose	51.0	25.6	76.6
Battery-powered electric vehicles (by primary energy source for electricity generation)			
U.S. mix	0.0	445.6	445.6
Coal-fired plants	0.0	545.6	545.6
Natural gas-fired	0.0	334.4	334.4
Nuclear plants	0.0	29.0	29.0
Solar power	0.0	1.3	1.3

SOURCE: M.A. Delucchi, Argonne National Laboratory, Argonne, IL, "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity," ANL/ESD/TM-22, vol. 1, 1991, table 9.

Chlorofluorocarbons and Stratospheric Ozone Depletion

While ozone in the air we breathe is harmful to health, a layer of ozone in the upper atmosphere shields the earth from harmful ultraviolet rays. Chlorofluorocarbons (CFCs) are chlorine containing halocarbons which until recently were widely used in automotive and other air conditioners. When released into the air, CFCs migrate to the stratosphere where they convert ozone to O_2, depleting the ozone layer. In 1987, the United States and most other nations signed the Montreal Protocol on substances that deplete the ozone layer, agreeing to phase out and eventually eliminate CFC production. The 1990 CAAA called for stopping CFC production in the United States by the end of 1994, but an extension was granted to one manufacturer until January 1996.

CFC-12 (dichlorofluoromethane), also known as freon-12, is the CFC previously installed in newly manufactured mobile air conditioners. Although air conditioners in new vehicles now contain a substitute (HFC-134a) that does not contain chlorine, leakage of CFC-12 from the air conditioners of older vehicles slows the progress toward complete elimination of CFC-12 emissions. CFC-12 emissions from all sources have decreased by 38 percent since 1989, and totaled 71 thousand metric tons in 1994. (USDOE 1995d)

CFCs are also potent greenhouse gases with thousands of times the warming potential of CO_2 per molecule. Because they destroy ozone, which is also a potent greenhouse gas, their net effect on climate change is uncertain. The HFC replacement refrigerant also is a greenhouse gas.

Water and Groundwater Contamination

Oil spills and improper disposal of used motor oil and other chemicals from transportation vehicles and facilities are major sources of both surface water and groundwater contamination. Large tanker spills, such as the 10 million gallons of crude oil discharged from the Exxon *Valdez* into Alaska's Prince William Sound in 1989, are the most visible examples. Depending on the concentration and nature of the pollution, the location of the spill, and the environmental resources affected, such spills can have major adverse environmental impacts. Far greater total volumes of oil and petroleum products enter the environment from smaller spills and the improper disposal of used motor oil. For example, it is estimated that the volume of used motor oil improperly dumped into sewers, drains, and soil annually is 15 to 20 times greater than the Exxon *Valdez* spill. From 1982 to 1992, spills from tankers into U.S. waters accounted for only a little more than one-third of all oil spilled. The cumulative effect of these smaller incidents can be significant and costly to clean up.

Other sources of water pollution include leaking above- and below-ground motor fuel storage tanks and pipelines, and runoff from transportation facilities and equipment. In 1993, EPA estimated that one-fifth of the 2 million or so underground fuel storage tanks in the United States that are subject to federal regulation were leaking. According to a 1993 American Petroleum Institute survey, 10 percent of petroleum transportation facilities with aboveground storage tanks reported groundwater contamination. (API 1994)

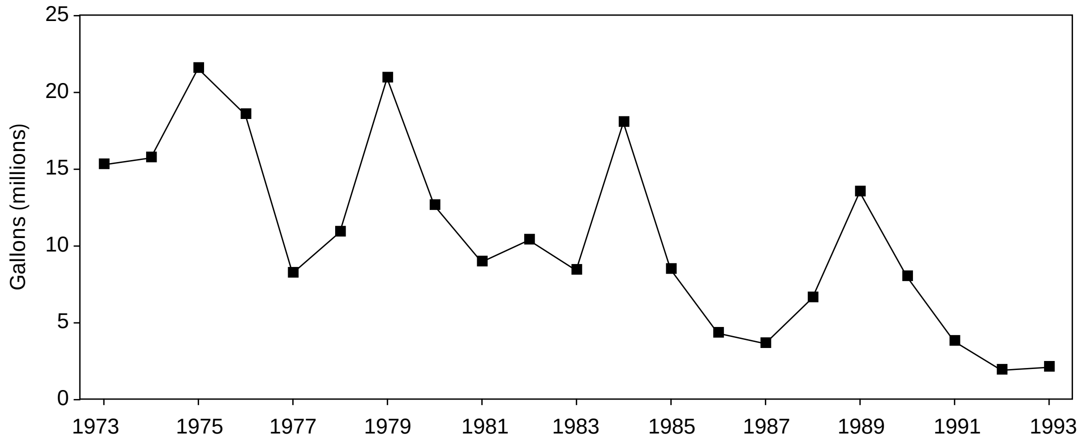
Substantial amounts of oil, grease, antifreeze, fuel, deicing materials, and other contaminants enter the environment from millions of operating vehicles. Additional contaminants come from pavement materials and pollutants from nontransportation sources that settle on highways, parking lots, airport runways, and other transportation facilities. Some of this material is carried by stormwater into rivers or other bodies of water, thus adding to the load of suspended solids, organic compounds, nitrogen, phosphorus, heavy metals, and other contaminants in the water. In general, relatively little is known about the volumes, composition, and impacts of pollution from these smaller, widely dispersed sources.

► Oil Spills into U.S. Waters

In 1994, the U.S. economy consumed 271 billion gallons of petroleum products. (USDOE 1995c, tables 5-8 and 5-11) The United States accounts for 25 percent of the world's oil usage and imports 45 percent of its total oil needs. As a result, 35 percent of the world's petroleum imports are destined for the United States. (USDOE 1995b, table 3-3) Because the transportation sector accounts for two-thirds of U.S. oil use, almost one-quarter of the oil shipped over the world's oceans is for use by the U.S. transportation system.

The median quantity of oil spilled annually in U.S. waters and reported was 9 million gallons or about 0.004 percent of the total amount used. The reported volume of oil spilled has trended downward in recent years despite gradually increasing consumption. The number of reported spills declined from approximately 10,000 per year in the 1970s to approximately 5,000 per year in the late 1980s. Since then, the number of reported spills has increased for spills of less than 1,000 gallons, possibly due to increased reporting under the Oil Pollution Act of 1990. The number of larger spills has continued to decline. While the volume of oil spilled has trended downward, periodic peaks result from large tanker spills (see figure 7-10). Part of the reason for the improvement can be attributed to laws and policies aimed at protecting U.S.

FIGURE 7-10: REPORTED VOLUME OF OIL SPILLED IN U.S. WATERS, 1973–93

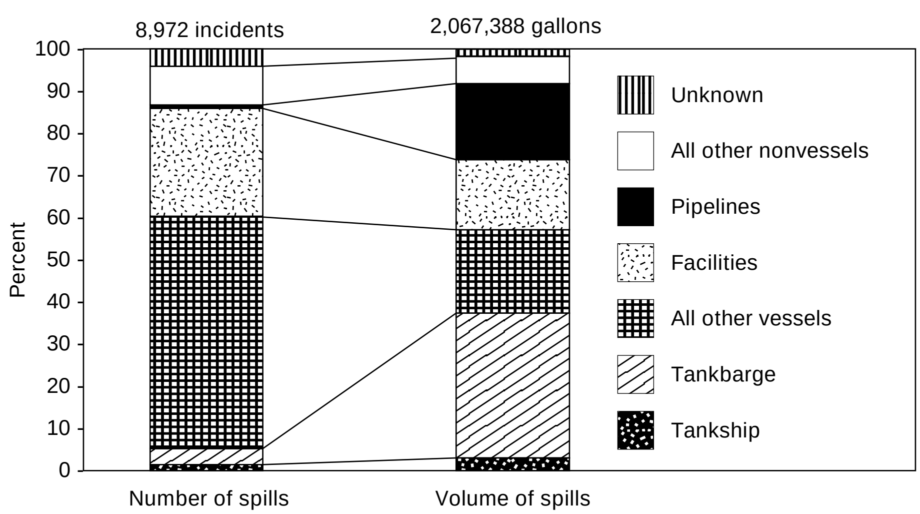


SOURCE: U.S. Department of Transportation, U.S. Coast Guard, *Pollution Incidents In and Around U.S. Waters* (Washington, DC: In press).

waters through fines, tighter regulations, and funding of research for pollution prevention and response.

The peaks shown in figure 7-10 suggest the skewed nature of spills, in which a small percentage of the spills account for most of the volume spilled. Of the 8,972 spills reported in 1993, 19 spills (just 2 percent) accounted for 1.5 million gallons (or 72 percent) of the 2 million gallons of oil entering the water that year (see figure 7-11). Of the remaining spills, 8,470 were less than 100 gallons each. Over the past 20

FIGURE 7-11: OIL SPILLS IN U.S. WATERS BY MAJOR SOURCE, 1993



SOURCE: U.S. Department of Transportation, U.S. Coast Guard, *Pollution Incidents In and Around U.S. Waters* (Washington, DC: In press).

years, oceangoing tanker spills accounted for 30 percent of the volume spilled, but only 5 percent of incidents. Three-quarters of all spills occurred during transportation; the remainder resulted from activities at fixed facilities.

The extent of adverse impact from spills depends on many additional factors aside from the quantity of oil. These include the characteristics of the spilled oil and receiving waters, the environmental sensitivity of the area, and the weather. Most spills occur in protected environments such as rivers, harbors, bays, and sounds, rather than on open seas. Of the approximately 221 million gallons reported spilled over the past 20 years, less than 15 percent were on the open ocean. (USDOT Coast Guard in press) The largest number and volume of spills reported occurred in internal waters.

► Improper Disposal of Used Motor Oil

The improper disposal of used motor oil is a widespread source of groundwater and surface water contamination. Automobile owners who change their own motor oil account for a significant portion of used oil dumping, disposing of up to 200 million gallons of oil annually; of this, as much as 120 million gallons may be dumped onto the ground or into storm drains and another 60 million gallons may be dumped into trash cans. (Novallo 1993) Annually, this is much more than the Exxon *Valdez* spill. (Anderson and Lear 1994)

Although a person may believe that dumping small amounts of oil is of little consequence, one quart of oil can taint the taste of 250,000 gallons of water and can create a 2-acre oil slick on lakes and streams. (Novallo 1993) Oil also contains additives that can oxidize during combustion to form corrosive acids, and used oil is often contaminated with heavy metals, chlorinated solvents, and harmful organic substances. EPA did not list used motor oil as a hazardous waste under the Resource Conservation and Recovery Act. It has promulgated, however, used oil handling standards for generators, transporters, processors, re-refiners, burners, and marketers. The standards only apply after used oil is collected and aggregated by public or private collection services. (Kreith 1994, 9.166)

According to EPA, only about 10 million gallons (5 percent) of the used motor oil generated by do-it-yourself oil changers was recycled in 1988. More recycling could decrease both the amount of used oil released into the environment and the amount of crude oil used for producing motor oil. Motor oil does not wear out; it merely becomes contaminated with residuals of fuel combustion and engine wear. Re-refining removes these contaminants from the oil and returns it to its original quality. (Novallo 1993, 109–112)

► Underground Storage Tanks

Groundwater contamination is often caused by leaks from underground storage tanks, such as those found at neighborhood gas stations. Most underground storage tanks are used by the transportation sector. Of these, about 49 percent are for retail motor vehicle fuels, 47 percent for petroleum storage, and 4 percent for chemical storage. According to EPA, about 1,000 confirmed releases are reported each week, and 20 percent of the 2 million regulated tanks may be leaking. (USEPA 1993, 14–15)

To remediate this type of contamination, the federal government established the Leaking Underground Storage Tanks program, which operates under the authority of Subtitle I of the Hazardous and Solid Waste Amendments Act of 1984 as amended by the Superfund Amendments and Reauthorization Act of 1986. The program's purpose is to achieve rapid and effective responses to releases from underground storage tanks containing petroleum and other hazardous substances.

The Strategic Targeting and Response System (STARS) is used to track releases and cleanup activities for underground storage tanks regulated under Subtitle I. (Other underground tanks are not included within the database.) The STARS database has been in place for a relatively short period of time, and the format of the data has changed somewhat, making it difficult to identify trends. Still, the number of active tanks regulated under Subtitle I has decreased since 1990, while closures and cleanup activities seem to show a peak in 1992–93.

► Aboveground Storage Tanks

In addition to their air emissions, spills from aboveground storage tanks (ASTs) are a source of groundwater contamination. ASTs at transportation facilities serve two primary functions: 1) to provide breakout storage or overflow relief at small pumping stations, or 2) to provide short-term storage at tank farms or distribution facilities. (API 1994) Spills from these facilities are often due to overfill, failure of tank bottoms, improper disposal of tank bottom mixtures, and leakage from piping associated with tanks.

A 1993 American Petroleum Institute (API) survey found improved spill prevention and reduced instances of environmentally unsound disposal practices at refining, marketing, and transportation facilities operated by API member companies. Of the 140 transportation facilities surveyed, 127 responded. This, however, represents only 8.7 percent of the transportation facilities operated by API members.

Mixtures of water and dissolved or entrained hydrocarbons accumulate at the bottom of aboveground storage tanks. These water-bottom mixtures once were routinely drained onto the ground. Now, 71 percent of the respondents said they used procedures to remove, recover, or properly dispose of the water-bottom material. Only 18 percent of the responding transportation facilities had established groundwater monitoring programs. The explanation is that many facilities, such as crude oil facilities, are located away from population centers. Ten percent of the respondents confirmed groundwater contamination.

The survey did not yield information about incident frequencies or accidental release volumes. Such information and more comprehensive surveys would be desirable.

► Runoff

Runoff from streets and parking lots is another source of water and groundwater contaminants. A study by the Federal Highway Administration (FHWA) identified the primary sources and constituents of highway runoff (see table 7-7). (USDOT FHWA 1987) Both the amount and nature of the materials are highly site-specific, depending on such factors as traffic characteristics, highway design, maintenance activities, surrounding land use, climate, and accidental spills. The study also determined that deposition from vehicles is the primary source of pollutants except during periods of ice and snow, when deicing chemicals and abrasives are the primary source. The FHWA study found that metals and sodium concentrations in topsoil next to highways could affect ecosystem processes.

FHWA analyzed runoff from 993 separate events at 31 sites in 11 states across the United States to determine the range of composition of highway stormwater runoff. (USDOT FHWA 1990, table 3) FHWA found that the only statistically significant distinction among the events in their sample was whether they were at rural or urban sites, the urban sites producing greater pollutant concentrations, as one might expect.

TABLE 7-7: CONSTITUENTS AND SOURCES OF HIGHWAY RUNOFF

Constituent	Primary sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Autobody rust, steel highway structures (e.g., guard rails), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or sodium ferrocyanide, Yellow Prussiate of Soda) used to keep deicing salt granular
Sodium, calcium	Deicing salts, grease
Chlorine	Deicing salts
Sulfate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
Polychlorinated biphenyls (PCBs), pesticides	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, and trucks hauling livestok and stockyard waste
Rubber	Tire wear

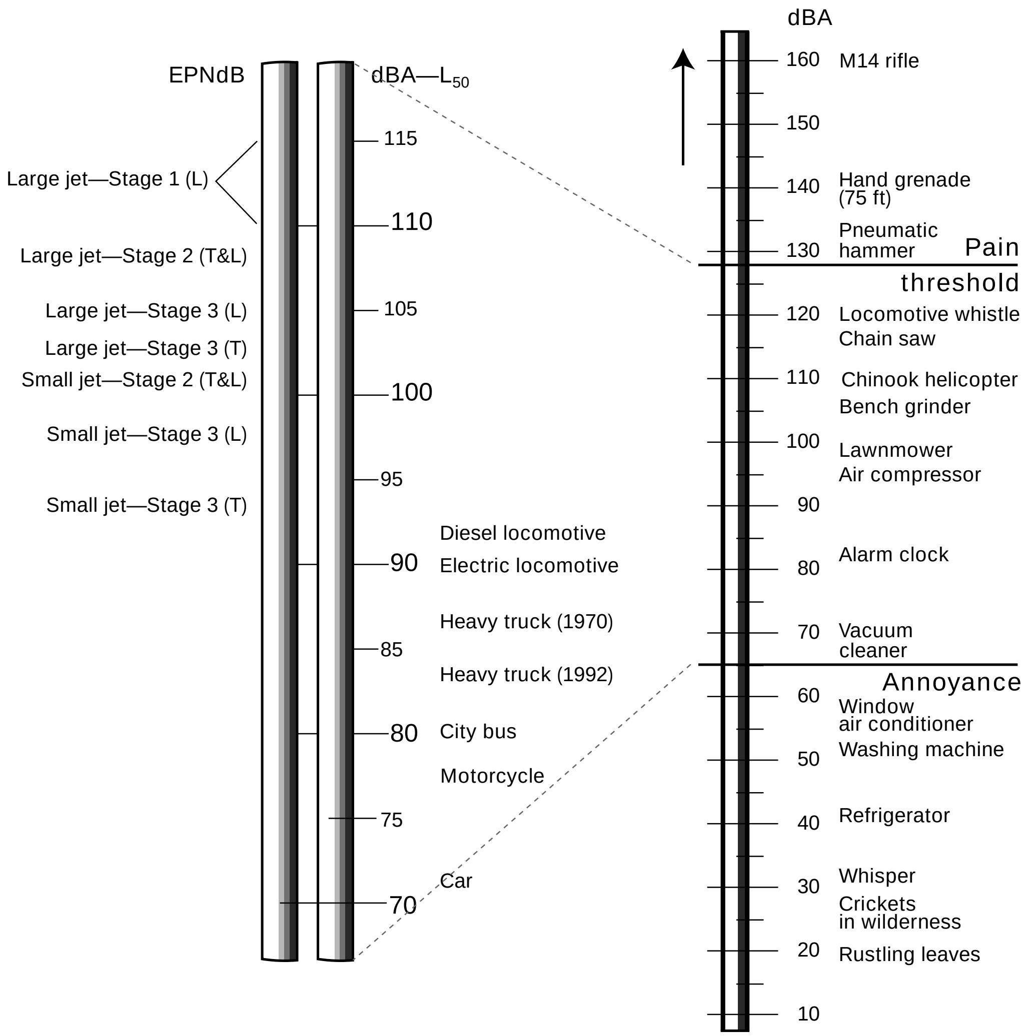
SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Sources and Migration of Highway Runoff Pollutants*, Technical Summary of Report No. FHWA/RD-84/060 (Washington, DC: 1987).

Noise

The transportation system is a pervasive source of noise in the United States. Intrusive noise—unwanted sound—is considered a form of pollution that can degrade the quality of life for those exposed. Sound is most often measured on a nonlinear scale in units of decibels. An adjusted scale, the A-weighted scale, emphasizes sound frequencies that people hear best. The measurement units in this scale are A-weighted decibels (dBA). On this scale, a 10-dBA increase in sound level is generally perceived by humans as a doubling of sound. Examples of sound sources and their typical noise levels are presented in figure 7-12.

The localized occurrence of noise makes it difficult to study national trends. Noise levels can vary drastically from site to site depending on noise sources, structures or natural terrain that block noise, and other factors. According to one estimate in the early 1980s, however, 37 per-

FIGURE 7-12: TRANSPORTATION NOISE LEVELS



KEY: EPNdB = Effective Perceived Noise Level used to measure aircraft flyover noise during a specified 10-second interval. Includes maximum audible sound level. Measurement is not comparable to A-weighted decibel scale.
dBA = A-weighted decibels (see text definition).
dBA—L_{50} = the sound level (measured in A-weighted decibels) that is exceeded by no more than 50 percent of the sample readings in the measurement time period. Peak sound level not necessarily measured. Noise measured at a point 7.5 meters from highway vehicles and locomotives. Unless noted, highway vehicles are 1992 European models.
L = landing noise over reference point 2,000 meters from runway threshold.
T = takeoff noise over reference point 6,500 meters from start of takeoff roll.
Small jet = commercial aircraft up to 100,000 lbs maximum takeoff weight.
Large jet = up to 1,000,000 lbs maximum takeoff weight.
Stage 1 = aircraft certified prior to 1969, before Federal Aviation Administration (FAA) noise regulations.
Stage 2 = aircraft sound level needed to meet FAA 1969 noise regulations. Now being phased out.
Stage 3 = aircraft sound level needed to meet FAA's more stringent 1975 noise regulations.

SOURCE: Aircraft noise—adapted from 14 Code of Federal Regulations, Part 36, appendix C; highway and railroad noise—P.M. Nelson, ed., *Transportation Noise Reference Book* (London, England: Butterworths, 1987); and Truls Berge, "Vehicle-Noise Emission Limits: Influence on Traffic Noise Levels Past and Future," *Noise Control Engineering Journal,* vol. 42, No. 2, March–April 1994; all other adapted from Ann Arbor Science Publishers, Inc., *Environmental Impact Data Book* (Ann Arbor, MI: 1979).

cent of the U.S. population was exposed to noise levels exceeding 55 dBA, 10 percent exceeding 60 dBA, 7 percent exceeding 65 dBA, 2 percent exceeding 70 dBA, and 0.4 percent exceeding 75 dBA. (OECD 1988, 44)

Annoyance, which is subjective, is probably the most prevalent effect of transportation noise. Transportation noise, especially noise from large aircraft, can interfere with sleep, and this, in turn, can adversely impact health. Minimum noise levels that disturb sleep range from 35 to 70 dBA, depending on the sleep stage and the age of the person.

Under the circumstances experienced by most people, transportation noise does not pose a permanent threat to hearing acuity. For hearing loss to occur, a person would have to stand about 10 to 20 feet (3 to 6 meters) from a highway lane carrying approximately 1,000 trucks per hour for 8 hours per day on a daily basis for many years. (Newman and Beattie 1985; USDOT FHWA 1980, 86)

► Highway Noise

Vehicles on the highway are the most pervasive source of noise from the transportation sector. The level of noise generated by highway traffic is a product of three factors: 1) traffic volume, 2) traffic speed, and 3) traffic mix (i.e., the number of trucks in the traffic flow). Noise from cars and light trucks is primarily caused by the sound of tires on the pavement, but noise from heavy trucks is a combination of engine, exhaust, and tire sounds.

Control Methods

Highway noise can be addressed through motor vehicle controls, land-use controls, and highway planning and design. Vehicle controls include quieter engine design, sound enclosures around engines, and better mufflers. Laws or regulations that require vehicle owners to properly maintain their vehicles are also considered vehicle control measures; such measures can produce a 5 to 10 dBA decrease in sound level. The Noise Control Act of 1972 authorizes EPA to regulate major sources of noise emissions, including transportation noise. In 1988, EPA established a noise emission standard for newly manufactured medium and heavy trucks with a gross vehicle weight of more than 4,525 pounds. (USDOT FHWA 1994) (The standard does not apply to vehicles too large to operate on highways.)

Land-use controls are sometimes used to reduce the impact of vehicular noise on residential areas, schools, churches, and other developments. Such controls may limit new development near highways or require soundproofing of buildings, erection of noise barriers, or other mitigation measures. The federal government has little authority to regulate land use, and such controls are usually implemented by state and local governments.

Noise also can be considered in highway planning and design. Studies can be conducted to determine whether an area will be seriously affected by highway construction or vehicle noise. In many cases, alternative routes can be selected if the projected noise levels exceed acceptable levels. By constructing a highway so that the line-of-sight between traffic and populated areas is obstructed, noise impacts can be avoided to some degree.

Noise barriers (solid obstructions erected between highways and areas such as residences, parks, and commercial buildings) impede highway traffic noises, reducing noise levels by as much as 10 to 15 decibels in some cases. (Cohn et al 1993, 69–74) As a result, noise barriers have become a popular method of highway traffic noise mitigation. From 1970 through 1989, 40 states and the Commonwealth of Puerto Rico constructed nearly 750 miles of barriers at a cost of nearly $650 million in 1992 dollars. (USDOT FHWA 1994)

► Aircraft Noise

Aircraft noise became a conspicuous problem in the United States with the advent of commercial jetliners in the 1960s. Research shows that hearing loss is not a cause for concern for aircraft passengers and the flight crew. Studies also show that there is no danger of permanent or even temporary hearing loss due to aircraft flyover. (Newman and Beattie 1985)

Speech interference is the primary source of annoyance from aircraft flyover. In addition to general annoyance, speech interference is a safety issue for crew members in the cockpit of aircraft. In situations where cockpit noises are above 88 dBA, special noise-canceling communications equipment should be used.

Some research shows that aircraft noise has minimal impact on farm animals. Wild animals have shown degrees of agitation when exposed to aircraft noise; however, a study involving wild birds demonstrated that this can be highly species-dependent.

Aircraft/Airport Noise Abatement and Regulation

In 1968, Congress gave the Federal Aviation Administration (FAA) authority to prescribe standards for measurement and regulation of aircraft noise so as to protect the public health and welfare. In 1969, FAA adopted Part 36 of the Federal Aviation Regulations (FARs), which established noise certification standards for turbojet and transport category aircraft. Part 36 required all future-design turbojet and large transport category aircraft to meet Stage 2 noise standards.[1] Current-production planes were excluded from this standard until 1974, when FAA demonstrated the feasibility of retrofitting current production aircraft to meet Stage 2 standards.

While Part 36 helped reduce noise from jet planes, the rapid expansion of commercial jet transport exposed more people to noise impacts. By 1974, for example, as many as 7 million people were severely affected by jet airplane noise. (USDOT FAA 1989) Thus, FAA required operators to install quieter engines or hushkits on Stage 1 aircraft by January 1, 1985. (Hushkits reduce fan and compressor noise by modifying various engine components and by adding acoustic treatment and noise suppressors.)

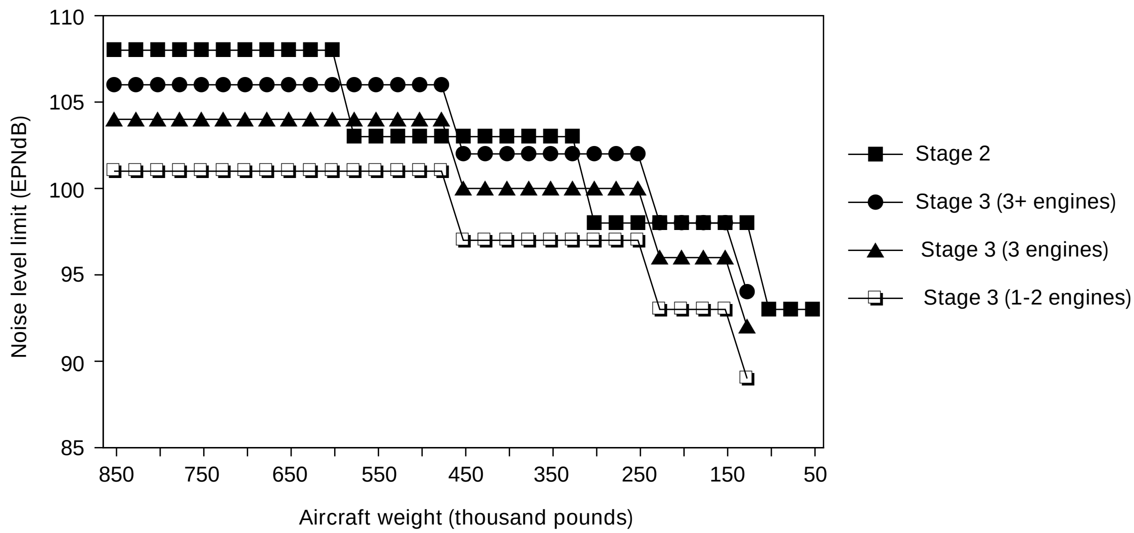
As jet travel increased, more stringent noise standards were adopted. Since March 1977, all newly type-certificated aircraft have been required to meet Stage 3 noise certification requirements where technologically feasible. These standards set limits on aircraft noise based on the number of engines in addition to weight and operation. In most cases, Stage 3 standards are more stringent than those for Stage 2—although there can be exceptions (see figure 7-13). Some airports imposed local operating restrictions to decrease the noise impacts of Stage 2 aircraft (such as phased elimination schedules, nighttime curfews, and noise budget allocations for carriers).

In 1990, Congress passed the Airport Noise and Capacity Act (ANCA), which calls for the phased elimination of civil, subsonic Stage 2 aircraft weighing over 75,000 pounds that use airports in the contiguous United States by December 31, 1999. (USDOT FAA 1994) Under an interim compliance schedule, operators can either reduce the percentage of Stage 2 aircraft or achieve a fleet composition percentage of Stage 3 aircraft by, for example, installing quieter engines or modifying Stage 2 aircraft engines with certified hushkits. ANCA also allows local airport operators to continue to use additional controls to reduce the impact of Stage 2 aircraft prior to the 1999 deadline.

According to FAA estimates, the Stage 2 and Stage 3 regulations have dramatically reduced the number of people exposed to aircraft day-night noise levels (DNL) of 65 dB or above. In

[1] See the key in figure 7-12 for an explanation of the stages of aircraft noise.

FIGURE 7-13: COMPARISON OF STAGES 2 AND 3 NOISE LIMITS FOR TAKE-OFF



NOTE: See key in figure 7-12 for an explanation of stages of aircraft noise.

SOURCE: Based on 14 Code of Federal Regulations, Part 36, appendix C.

1975, 7 million people lived within DNL 65 dB contours. By 1990, the number of people within these contours was only 2.7 million. FAA estimates that this number will decrease to 0.4 million by 2000 after the final phase of the Stage 2 ban goes into effect. (USDOT FAA 1994)

Airport noise compatibility planning is another way to reduce noise annoyance for areas around airports and under aircraft flight patterns. The objective of the planning is to help areas near airports take noise impacts into account in their land-use and development decisions.

Under FAR 150, federal grants are available to airports for preparation of airport noise exposure maps and airport noise compatibility programs. FAA has issued criteria to be used by airports that elect to participate in the program. As of November 1995, 173 airports had approved Noise Compatibility Programs, and about 220 airports were active within the Part 150 program. (Hixson 1995)

Solid Waste

Discarded vehicles or parts and obsolete or abandoned infrastructure (e.g., pavement scraped off highways and abandoned rail line materials) account for most of the solid waste generated by the transportation sector. Much of the waste is put in landfills, but a significant amount of scrap from old vehicles, tires, car batteries, and pavement is recycled. In addition to the solid waste generated by transportation, a significant volume of waste (hazardous and otherwise) is shipped by rail, truck, and vessel. Solid waste can also be generated in the maintenance of transportation infrastructure. Examples are silt and other material dredged from ports and harbors to maintain navigation channels. Disposal of this material, especially when contaminated can be challenging (see box 7-3).

Box 7-3: Dredging of Sediments in Ports and Harbors

In 1992, more than 3 billion tons of cargo moved into and out of U.S. ports. Essential for trade and commerce, these ports handle 95 percent (by weight) of all U.S. exports and imports. Ports and port activities, however, affect the nation's coastal, ocean, and freshwater resources. One environmental issue is dredged sediments. In order to accommodate large cargo ships, navigation channels must be dredged and siltation removed from the harbor floor. Although estimates vary widely, one study concluded that about 400 million cubic yards of material are removed each year to maintain the depth of navigation channels and shipping berths. The current permitting process results in the special handling of about 5 percent of dredged material classified as contaminated.

Siltation is a common problem because many of our nation's ports (e.g., New York, New Orleans, Baltimore, and Portland) were built at the mouth of river systems that deliver silt that settles in port channels, making regular dredging a necessity. As ship size and speed have increased, so too have the requirements for channel depth. For example, in the 1970s, a depth of 35 feet was considered adequate to handle most maritime trade. Today, container ships require channel depths of 45 to 50 feet; bulk carriers may require water depths of 60 to 65 feet. For all ports, particularly those with tributary river systems, maintaining channel depth provides a challenge.

Uncontaminated dredged material can be used beneficially for beach nourishment, wetland creation, and as caps for landfills, or it can be dumped in certain disposal sites in open waters. Contaminated material, on the other hand, may have to be treated to reduce its toxicity and managed in special ways, increasing the costs of navigational dredging. Contaminates include heavy metals and other pollutants, such as dioxins and polychlorinated biphenyl, that are or have historically been discharged into water and air. Contributing sources are industrial facilities within ports and upstream, and nonpoint sources such as transportation and agriculture. For example, bottom sediments in many harbors and rivers of the Great Lakes ecosystem have been found to contain bioaccumulated toxic substances from past industrial discharges. Contaminates reduce or injure fish and wildlife populations. Improper disposal of contaminated material can present costly environmental and human health risks.

Dredge material management is a contentious issue. In some instances, the presence of contaminated sediment has delayed dredging, thereby affecting waterborne commerce.[1] Uncertainties exist about how best to determine the extent of contamination in sediments, and there is debate about appropriate management options. Indiscriminate dumping in the ocean was once a common way to dispose of sediment but is no longer permitted. Current alternatives include upland disposal and disposal in confined areas within ports and harbors (such as underwater in covered pits or by constructing islands). Highly contaminated materials may require special remediation to remove or treat the contaminants before disposal. A National Research Council study, expected to be issued in late 1996, is examining best management practices and technologies and other issues relevant to contaminated sediments.

National and state regulations have been developed to address dredging and appropriate sediment management to maintain the environmental integrity of the nation's coastal resources. Under statutes, such as the Clean Water Act (CWA) and the Marine Protection, Research, and Sanctuaries Act (MPRSA), a number of agencies have been given authority for various stages of the dredging and disposal process. Under the MPRSA, for instance, the U.S. Army Corps of Engineers issues permits covering dredged materials disposed in most coastal waters and the open ocean; the Environmental Protection Agency has review authority, designates specific ocean disposal sites, and established the environmental impact criteria used by the Corps of Engineers in the permit review process.

[1] Council on Environmental Quality, Office of the President, *Twenty-Fourth Annual Report* (Washington, DC: U.S. Government Printing Office, 1993).

(continued)

Box 7-3 (cont'd): Dredging of Sediments in Ports and Harbors

Disposal in most freshwater areas and wetlands, estuaries, and coastal waters is regulated under the CWA. Regulations setting quantitative sediment quality criteria have been debated for a decade and were finally proposed in 1994.

Recognizing a need for improvements in the dredging review process, Secretary of Transportation Federico Peña convened an Interagency Working Group on the Dredging Process in October 1993.[2] The Group's *Action Plan for Improvement*, submitted in December 1994, resulted in the establishment of an interagency National Dredging Team and regional teams. The teams are helping to implement the action plan's comprehensive recommendations. The aim is to establish a more timely, efficient, and predictable dredging process.

[2] U.S. Department of Transportation, Maritime Administration, *Report to the Secretary of Transportation, The Dredging Process in the United States: An Action Plan for Improvement* (Washington, DC: December 1994).

► Highway Vehicle Scrappage

Dismantlers have long collected junk cars and spare parts for resale, reconditioning, or recycling. With the introduction of shredding in the 1960s, it has became more cost-effective to recycle vehicles. By 1995, 94 percent of retired vehicles were recycled, and 90 percent were scrapped at shredders. (Curlee et al 1995; AAMA 1995, 55; Holt 1993)

According to Oak Ridge National Laboratory, approximately 12.8 million tons of material were generated from retired automobiles from June 1993 to June 1994. About 73 percent of this material (9.4 million tons) was recycled. The remaining 3.5 million tons was placed in landfills.

The increase in highway vehicle recycling over the last few decades has reduced the volume of waste that would otherwise be placed in landfills. Recent trends in the composition of passenger vehicles, however, have begun to make current recycling practices less viable economically, thereby forcing vehicle manufacturers, recyclers, and other organizations to find new technologies and procedures for recycling highway vehicles.

To improve fuel efficiency, manufacturers reduced the weight of vehicles. Since 1976, the weight of the typical family vehicle decreased from 3,761 pounds to 3,169 pounds, an average decrease of 592 pounds (see table 7-8). Much of this reduction came through less use of steel,

Table 7-8: Composition of a Typical Passenger Vehicle, 1976–94 (pounds of material)

Year	Ferrous	Aluminum	Other nonferrous	Thermoplastics	Thermosets	Other materials	Total
1976	2,785.0	85.5	101.0	87.6	74.9	626.5	3,760.5
1980	2,423.5	130.0	71.0	97.3	97.7	543.5	3,363.0
1985	2,269.0	138.0	62.0	128.3	83.2	506.5	3,187.0
1990	1,985.0	158.5	65.0	128.3	93.7	465.0	2,895.5
1994	2,145.0	182.0	58.0	152.4	92.6	539.0	3,169.0

SOURCE: *Ward's Automotive*, annual editions, 1976–1994.

iron, and other metals, and greater use of such lighter weight materials as plastics and plastic composites. Unfortunately, metals are the most cost-effective materials to recycle, while plastics, rubber, glass, and other materials are most often regarded as "fluff" or "automobile shredder residue" (ASR) and placed in landfills or incinerated. As the amount of recyclable metals decreases, recycling becomes less profitable.

New technologies that could increase the cost-effectiveness of recycling are under development. For example, one Maryland company is developing a computerized dismantling facility. The computer helps determine which vehicles, or which vehicle parts, are economically reclaimable, based on make, model, year of the vehicle, estimated time to remove recyclable parts, and the market value of these parts. (Holt 1993) Oils, lubricants, and other liquids are extracted for off-site reprocessing. Recovered fuels are used on-site for power generation; most plastics, oils, and hydraulic fluids are converted into natural gas and used for fueling the on-site electric cogeneration system. The remaining hulk is separated from hazardous materials and liquids, compressed, and bundled for resale.

Some firms have conducted research to find uses for ASR and to develop processes for recovering these materials in a cost-effective manner. Perhaps, in the future, innovative recycling technology will make a significant impact on the amount of ASR in landfills.

Automobile designers have begun to find ways to make automobiles more recyclable and to use recycled materials in new autos. Much of this effort has been propelled by expectations that Germany and some other European countries may eventually require auto manufacturers to take back their cars for recycling or disposal when their useful life ends. Such proposals, if adopted, could apply to cars imported into Germany or other countries with take-back requirements, as well as to their domestic automakers. (Kinraid 1995)

► Lead-Acid Batteries

Lead-acid batteries from automobiles are another source of solid and liquid waste from the transportation sector. The Battery Council International estimates that, overall, 98 percent of obsolete lead-acid batteries from vehicles were recycled in 1990 and 97 percent were recycled in 1991. (Kreith 1994) Still, the hazardous nature of these batteries suggests that even higher recovery rates would be desirable. It is estimated that lead from automobile batteries accounts for about two-thirds of the lead (by weight) in municipal solid waste sites. (Kreith 1994)

A typical automobile battery has a useful lifetime of three to four years. It contains 18 pounds of lead and lead dioxide, 9 pounds of sulfuric acid (about 1 gallon), 3 pounds of polypropylene plastic casing, 3 pounds of polyvinyl chloride rubber separators, and about 3 pounds of various chemical sulfates and oxides. Lead from used batteries is reclaimed at smelters, which rely on used batteries for more than 70 percent of their lead supply. Sulfuric acid recovered from batteries can be used in fertilizer or neutralized for disposal, and the plastic battery cases can be reused or recycled to form other plastic products.

Lead wastes are hazardous, and can be absorbed through ingestion or inhalation. Lead settles in body organs, often causing liver and kidney damage in adults and neurological damage to children. Lead from landfilled batteries can leach into groundwater or contaminate surrounding soil. For this reason, EPA classified lead-acid batteries as hazardous waste in 1985. Also, as of February 1993, 41 states had passed legislation on lead-acid batteries. Regulations include such measures as banning disposal of lead-acid batteries in landfills and incinerators, establishing requirements for retailers and collection facilities that accept spent batteries, imposing fines to enforce regulations, and requiring deposit fees for the sale of new batteries, which can be recovered on return of the spent battery.

Tires

Used tires comprise a large part of the solid waste generated by the transportation sector. No industry group or governmental agency monitors scrap tire disposal in the United States. Therefore, estimates of used tire generation are based on tire production. (USEPA 1991)

In 1990, an estimated 188 million tires were placed in landfills or stockpiles, or dumped illegally (see figure 7-14).Tires are a significant problem in landfills. The tires often rise to the landfill surface as other materials around them settle. The uncovered tires can be breeding grounds for mosquitoes and other insects. Piles of tires sometimes ignite and burn, releasing toxic smoke and fumes. Burning tires emit criteria air pollutants, metals, and unburned organics. (USEPA 1991) Burning tires are difficult to extinguish, and the related residue can cause groundwater contamination. Several large stockpile fires in the mid-1980s prompted interest in alternative uses for scrap tires.

It has been estimated that only about 22 percent of the tires that were scrapped in 1990 were recycled. The recycled tires were processed in two primary ways: fuel combustion (26 million) and processed-tire products (16 million). Another 300,000 tires were reused in whole-tire applications. (While there are many uses for scrap tires—crash barriers, retaining walls, artificial reefs, playground equipment, landscaping material, and other applications—they have not developed into widely marketed products.) An additional 12 million tires were exported to other countries (see figure 7-14).

Burned as fuel, tires have an energy content of about 15,000 Btu per pound, somewhat higher than coal (6,000 to 13,000 Btu). Tires are also compact, consistent in composition, and low in moisture content.

Processed-tire applications include pyrolysis products, shredded embankment material, various molded rubber products, and crumb rubber for asphalt paving. Of these, pyrolysis and crumb rubber are the most common.

Pyrolysis thermally breaks scrap tires down into three marketable products—pyrolytic gas, oil, and char. The gas has a heat value similar to natural gas. The oils can be used for gasoline additives and fuel oil, and char can be substituted for carbon black in some applications. EPA maintains that pyrolysis units will have minimal air pollution impacts, because most of the pyrogas generated in the pyrolysis process is burned as fuel, and organic compounds are destroyed during burning. (USEPA 1991)

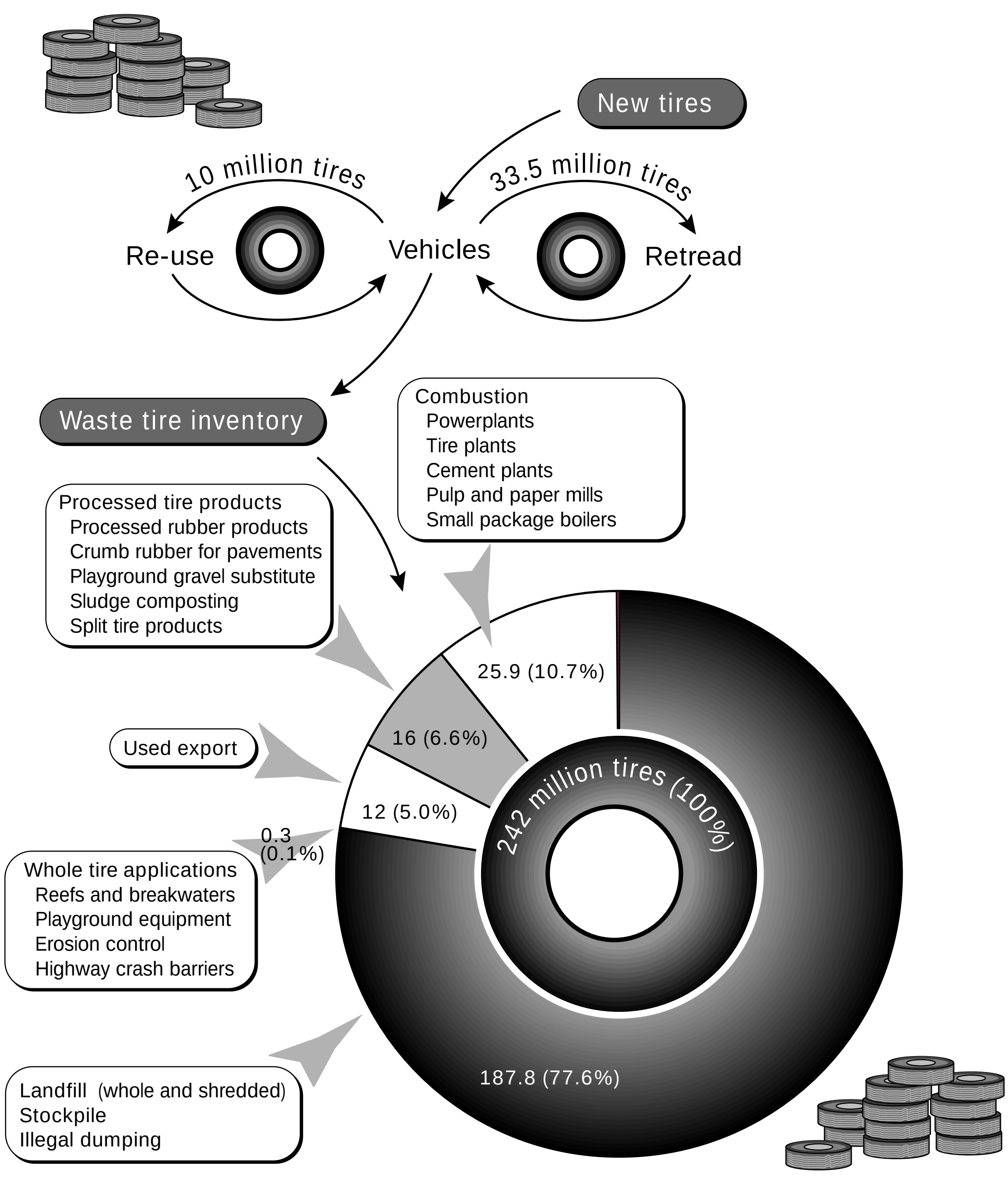
Crumb rubber modifier (CRM) is primarily used to produce asphalt rubber and rubber modified hot mix asphalt (RUMAC). Asphalt rubber is a combination of asphalt cement binder and CRM and is used in sealants, thin surface treatments, and hot mix asphalt (HMA). RUMAC is used in hot mix asphalt only (see next section). (USDOT FHWA and USEPA 1993, 4)

Use of asphalt pavement containing recycled rubber has been encouraged through provisions in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). ISTEA prohibits disapproval of highway projects on grounds of use of asphalt pavement with recycled rubber. It requires studies on the performance and recyclability of asphalt pavement containing recycled rubber and evaluation of the environmental impacts of its use. ISTEA provisions setting minimum utilization requirements for recycled rubber in asphalt pavement were repealed by Congress in the 1995 National Highway System Designation Act.

Asphalt and Concrete Pavement

Asphalt and concrete pavement removed from roadways constitute a significant portion of the solid waste produced from transportation infrastructure. Fortunately, this material can be reclaimed and used in a number of transportation-related applications. Estimates vary about

FIGURE 7-14: DISPOSITION OF U.S. SCRAP TIRES, 1990



SOURCE: U.S. Environmental Protection Agency, Solid Waste and Emergency Response, *Summary of Markets for Scrap Tires* (Washington, DC: 1991).

the total amount of reclaimed asphalt pavement (RAP) generated each year. A 1994 estimate put the quantity of RAP at about 45 million metric tons per year. A study by FHWA published in 1979 estimated that 90.5 million metric tons were removed annually. (USDOT FHWA 1995, 6) The Environmental Protection Agency estimates that more than 80 percent of removed asphalt pavement is reused in highway applications, and less than 20 percent is placed in landfills. (USDOT FHWA 1995, 6, 13)

Reclaimed Asphalt Pavement

Reclaimed asphalt pavement is used for, among other things, resurfacing, aggregate for roadway and shoulder base, shoulder surfacing and widening, driveway maintenance, surfacing under traffic barriers, ditch linings, and pavement repairs. RAP is typically recycled in three ways: HMA prepared off-site at a plant, hot in-place recycling (HIPR), and cold in-place recycling (CIPR).

An estimated one-third of the RAP generated annually is used in HMA production. (USDOT FHWA 1995, 13) RAP content in recycled HMA produced with conventional technology typically is in the range of 10 to 20 percent. Hot mix materials with a far higher RAP content can be produced, however, without adverse engineering or significant environmental problems. (USDOT FHWA and USEPA 1993, 27)

The initial construction cost of HMA recycling projects can be 15 to 30 percent less than traditional paving approaches. (USDOT FHWA and USEPA 1993, 14) Savings vary depending on project and plant location, materials availability and proximity, and asphalt cement prices. Since most recycling projects are relatively recent, adequate performance data for estimating life-cycle costs is often not available.

According to the National Asphalt Pavement Association, almost half of the HMA producers in the United States used some recycled asphalt in 1986. More recently, FHWA reported that, among state highway agencies that responded to a request for information, the use of RAP for HMA ranged from 7 percent in Texas to 75 percent in Florida. (USDOT FHWA 1995, 6)

HIPR is an on-site process to rehabilitate existing pavement. The existing pavement is heated and milled, mixed with new material, placed, and compacted by the recycling train. Currently, this technique only is used to remedy problems with the surface course on pavement not needing structural improvement.

According to the American Recycling and Reclaiming Association (ARRA), HIPR was used to recycle approximately 545,000 metric tons of RAP in 1991. The cost of using this technique has varied significantly from a 16 percent increase over conventional methods to a 40 percent savings, with recent reports finding cost savings of less than 10 percent. (USDOT FHWA 1995, 16)

In another on-site process, CIPR, the existing pavement is milled, mixed, and placed without added heating. The placed material is then cured, compacted, cured again, and covered with a wearing surface. ARRA estimates that 2,060,000 metric tons of RAP were processed using this technology in 1991. (USDOT FHWA 1995)

Reclaimed Concrete Pavement

About 3 million metric tons of reclaimed concrete pavement are used annually. (USDOT FHWA 1995, 23) It is most commonly used as an aggregate subbase or base course, but at least two states reported use in hot mix asphalt.

► Transportation of Hazardous Materials

A large volume of hazardous materials is shipped each year, posing risks of accidents and damage to the environment. For this reason, the government regulates the transport of hazardous materials and monitors spills. Table 7-9 summarizes causes and consequences of hazardous materials incidents in 1994. The number of incidents rose from about 6,000 in 1985 to 16,092 in 1994. The 1994 incidents resulted in 11 deaths, 577 injuries, and $37 million in damages. (The figure for water transportation does not include spills from bulk containers, i.e., tankers and barges.) Although the number of incidents has grown, it is far from certain that the incident occurrence rate is increasing. Improved reporting explains part of the increase in reported incidents. Additionally, the growth in incidents also may be caused by increased economic activity. Both ton-miles and vehicle-miles of freight rose over the past decade. While it is reasonable to assume that shipments of hazardous materials also increased, reliable statistics are not available.

Another factor in the growth of incidents is the rise in nonbulk shipments of hazardous materials, including those by parcel services. Indeed, incidents from bulk shipments have remained flat over time, whereas those from nonbulk shipments have grown steadily. Because incidents include any unintentional release of hazardous materials during the course of transportation, many of the nonbulk incidents were spills that did not spread beyond the vehicle. While the total number of incidents increased, the number of serious incidents remained constant. (In this context, a serious incident is one that involves a fatality, major injury, closure of a major transportation artery or facility, evacuation of six or more persons, or a vehicle accident or derailment.) It is likely that minor incidents were previously underreported and that minor, nonbulk incidents account for at least some of the rise.

The bottom half of table 7-9 shows the consequences of hazardous materials incidents. As with the number of incidents, these numbers have trended upward since 1985, although at a slower pace and more erratically. Most of the numbers

TABLE 7-9: HAZARDOUS MATERIALS INCIDENT STATISTICS, 1994

Causes	Air	Highway	Railway	Water	Total incidents
Human error	787	12,189	539	4	13,519
Package failure	120	1,408	556	1	2,085
Vehicle accident/derailment	0	246	52	0	298
Other	23	156	10	1	190
Consequences					
Incidents	930	13,999	1,157	6	16,092
Deaths	0	11	0	0	11
Injuries	57	425	95	0	577
Number of evacuations	29	255	31	1	316
Number of people evacuated	368	7,984	10,015	25	18,392
Damages	$177,543	$25,248,950	$18,673,002	$92,003	$44,191,498

SOURCE: U.S. Department of Transportation, Research and Special Programs Administration, Hazardous Materials Information System.

are based on information collected within 30 days of the incident, which affects the damage figures. Damages that are not assessed until later are not included, which potentially overlooks costly environmental remediation.

Land-Use and Habitat Effects of Transportation

Transportation has important direct and indirect impacts on land use and environmental habitats: 1) land is used directly for transportation infrastructure, and 2) other development may be stimulated by the construction or expansion of transportation infrastructure. Both of these transportation-related forms of development have the potential to reduce and/or fragment wildlife habitat and disrupt ecosystems.

► Land Requirements for Transportation Infrastructure

The transportation infrastructure of the United States is extensive. The highway system reaches all but the most remote and unpopulated parts of the country; most small cities have a rail line passing though them, and airports of all sizes are common throughout the United States. In addition, ports, intermodal facilities, pipeline facilities (where such facilities are above ground), rail yards, and other transportation infrastructure also require land.

According to one estimate, the land devoted to roads in 1991 totaled approximately 20,627 square miles, and land devoted to parking ranged from 1,910 to 3,035 square miles. (These estimates include only the paved portion of the highway. Other portions of highway right-of-way such as land between divided Interstates and the cleared areas outside the shoulders of highways are not included.) (Delucchi 1995)

Like other forms of development, transportation infrastructure—through direct use of the land and through land fragmentation—reduces the amount of land usable by wildlife and occupied by vegetation. Currently, national-level information about the cumulative impacts of this infrastructure on ecological systems is very limited. Most transportation-related impacts on habitats are studied at the local level. The federal government requires that Environmental Impact Statements be prepared for federally funded development projects that could have a significant impact on the environment. These statements address impacts on mammals, birds, aquatic life forms, endangered species, air quality, water quality, ambient noise levels, cultural and historical sites, and other aspects of the environment. The environmental impact statement process does not prohibit development nor require any specific decision, but relies on full disclosure to identify and assess impacts. Mitigation measures must be considered to minimize impacts and a monitoring program adopted where appropriate.

► Habitat Fragmentation

Transportation infrastructure can form barriers to wildlife, especially highways and rail lines. While highways and rail lines do not occupy much of the area of the land they traverse, their linear nature divides wildlife habitat into smaller, more isolated units of land or creates barriers between functional areas. Impacts such as traffic noise, emissions of xenobiotic substances, artificial lighting, and vehicle-fauna collisions also affect species in fragmented areas. Mitigation measures, such as lowering speed limits to reduce noise levels, erecting warning signs and fences to avoid collisions, and constructing ecoducts (fauna bridges and tunnels) to allow freer movement of fauna between isolated fragments are sometimes used. Also, countries such as the

Netherlands employ compensatory programs to replace destroyed habitats or improve marginal habitats. (Van Bohemen 1995)

► Wetlands

Wetlands can be adversely affected by most kinds of development. In the past, wetlands were widely viewed as unproductive tracts of land and were drained so that they could be put to more "profitable" use. In the last few decades, it has become clear that wetlands perform important functions for humans, fish and shellfish, and wildlife. Wetlands provide flood conveyance, act as erosion, wind, and wave barriers, facilitate sediment replenishment, provide habitat for waterlife, waterfowl, mammals, and reptiles, improve water quality by removing nutrients and some chemical contaminants, and are sometimes a source of timber. They may also have recreational, educational, and historical value. As one study put it: "many of the beneficial functions of wetlands accrue to the larger populace but not to the land-owner who is in a position to capture only a portion of the product of wetlands." (Anderson and Rockel 1991)

In an attempt to decrease the rate of loss of the nation's wetlands, the federal government has implemented a policy aimed at achieving the goal of "no net loss" of wetlands. This is often achieved by requiring some kind of compensatory mitigation such as wetland mitigation banking or fee-based compensatory mitigation. (Environmental Law Institute and Institute for Water Resources 1994)

Mitigation banks have been set up to offset losses of wetlands from construction or other forms of development. Using a system of credits and other marketable instruments, mitigation banking makes it possible for developers to convert wetlands to other uses if corresponding activities take place elsewhere to restore, protect, or create other wetlands of comparable value. As of the summer of 1992, 24 of the 46 existing wetland mitigation banks in the United States were developed for transportation-related mitigation; 18 of these were operated by state departments of transportation to meet continuing needs for compensatory mitigation. (Environmental Law Institute and Institute for Water Resources 1994) Most other transportation-related banks were constructed to offset impacts of waterway/harbor dredging and port facility expansion. Of the 59 banks proposed in 1992, 19 were for transportation purposes.

► Transportation and Land-Use Interactions

Transportation systems can also impact the environment indirectly by affecting how land is subsequently developed and used. Transportation and other forms of land use affect each other, and the relationship between them has important implications for the evolution of urban environments. Chapter 8 discusses the air quality implications of the interaction between transportation and land use in some detail.

By making access between places easier and cheaper, new transportation options can not only encourage relatively rapid changes in travel behavior but can also encourage, and are often a necessary component of, new patterns of industrial, commercial, and residential growth. Businesses may relocate or open new premises, and households may move to new residential areas made more accessible to a region's employment, retail, recreational, and institutional centers of activity. Over time these changes in land use generate new travel demands, possibly accompanied by new patterns of traffic congestion, which in turn encourage additional transportation capacity.

Isolating transportation's role in the land development process is difficult, especially within urban settings. (Southworth 1995) Much of the residential development in the United States since World War II has been low in density and located in the suburbs. It has been spurred by the low cost of driving and the nation's extensive highway building programs. Consequently, our larger urbanized areas expanded considerably. Employment similarly migrated away from congested and high-rent central business districts, and many Americans now live and work within multicentered metropolitan areas.

Between 1982 and 1992, built up and urban land in the United States increased by 14 million acres, according to the U.S. Department of Agriculture. As a result, developed land in the United States totaled 92.4 million acres, roughly 5 percent of the U.S. land area not including Alaska. (US Department of Agriculture n.d.)

Future development patterns will depend in part on societal choices about highways, public transit, and other transportation systems, and the costs of constructing and maintaining these systems. Technological and other changes will also affect choices. For example, the information society could alter the transportation and land-use relationship in the coming century. (US Congress OTA 1995b, 106) A growing number of service and information-based companies already find themselves no longer tied to the geographic location of their key resource inputs or to local markets for their products. Industrial practices such as just-in-time scheduling may also affect the siting needs of companies as well as their use of freight vehicles. How the nation's households and companies will respond to telecommuting, teleshopping, and other potential travel-reducing options remains an open question.

Costs and Benefits of Environmental Controls

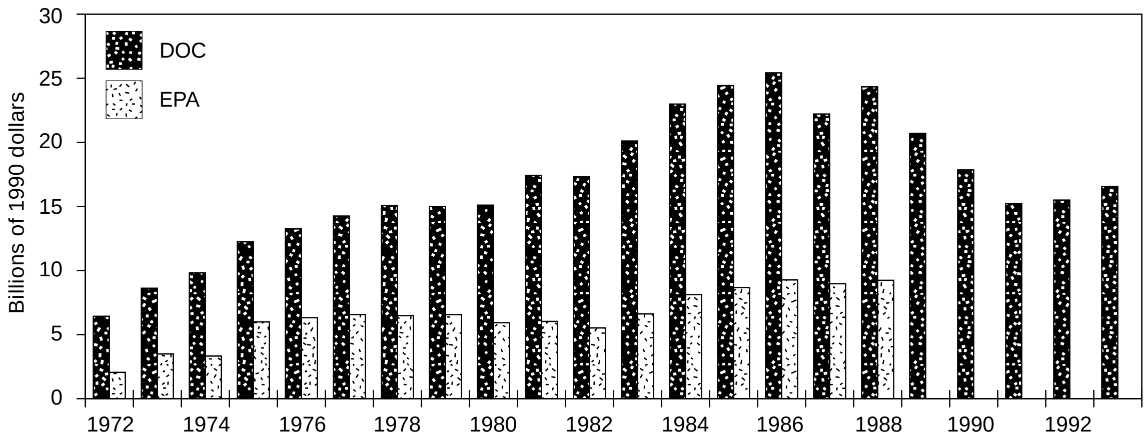
The benefits arising from emissions reductions, noise abatement, and other environmental protection actions are not free. They come at a cost of resources that could be used for personal expenditures by consumers, investments by business, or spending by governments for other objectives such as national defense and medical research. As a result, deciding on a level of environmental protection can require choices between a cleaner environment and other societal goals. As pointed out in chapter 6, the environmental management system that has evolved in the United States increasingly seeks to equate the cost of the next improvement in environmental quality with the benefits it provides. Unfortunately, this is more easily said than done. The benefits of environmental protection, while real, are often very difficult to quantify in economic terms. The direct costs of pollution abatement and control are easier to identify, although estimates vary substantially.

According to the U.S. Department of Commerce (DOC), consumers, businesses, and governments in the United States spent $17.2 billion (in 1994 dollars) on air and water pollution controls for highway transportation in 1993. (Rutledge and Vogan 1995, table 3) (An EPA estimate for 1972 to 1988 was roughly half the DOC number. In part, this difference reflects EPA's estimates of benefits—such as greater fuel economy of vehicles—stemming from government regulations.) (See figure 7-15.)

DOC did not estimate pollution abatement costs for other transportation modes. Upstream costs to control pollution from facilities operated by petroleum refineries or vehicle manufacturers are not included in the $17.2 billion. DOC estimated the petroleum industry's annual capital plus operating costs for environmental protection at $2 billion to $3 billion over the past decade, while the industry estimates its expenditures at up to 80 percent more, depending on the year in question. (Perkins 1991)

DOC attributed $16.6 billion of its $17.2 billion cost estimate to motor vehicle emissions controls. The remaining amount was spent on state and local highway erosion control pro-

FIGURE 7-15: MOBILE SOURCE EMISSIONS CONTROL COSTS IN THE UNITED STATES, 1972–93



SOURCES: U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, *Environmental Investments: The Cost of a Clean Environment,* EPA-230-11-90-083 (Washington, DC: 1990), tables 3-1A and 3-2A; G.L. Rutledge and C.R. Vogan, "Pollution and Abatement and Control Expenditures, 1993," *Survey of Current Business,* vol. 75, No. 5, May 1995, table 3, pp. 36–49; and G.L. Rutledge and C.R. Vogan, "Pollution and Abatement and Control Expenditures, 1972–92," *Survey of Current Business,* vol. 74, No. 5, May 1994, table 3, pp. 36–49.

grams. (Other costs borne by highway transportation for environmental compliance, such as noise abatement, were not addressed.) DOC estimated that businesses paid 42 percent of the \$17.2 billion, while consumers paid 54 percent in the form of higher vehicle prices. By dividing the \$16.6 billion for motor vehicle emissions controls by the 14.2 million vehicles sold in 1993, a rough estimate of \$1,150 per vehicle for emissions control costs emerges. Of course, costs vary greatly by type of vehicle and even by place, because California has stricter vehicle emission standards than the rest of the country.

While the expense of motor vehicle pollution controls is considerable, the benefits are also very large, if more difficult to quantify. As documented earlier in this chapter and in chapter 8, U.S. cities would be far more polluted than they are today had there not been significant reductions in emissions from the transportation sector since 1970. Total CO emissions would be 2.5 times as great, VOC emissions would be twice as great, and NO_x emissions would be 40 percent greater. Nearly all the reduction in emissions from the transportation sector is the result of emissions standards for new highway vehicles and cleaner fuel requirements.

Clearly, U.S. air quality would be far worse had these transportation emissions reductions not been made. To estimate the benefits in a way that is truly comparable to the corresponding cost estimates just presented, three more steps would have to be taken. Emissions would have to be translated into air quality, air quality into impacts on health, flora, fauna, and infrastructure, and these impacts monetized. The Environmental Protection Agency is undertaking a comprehensive analysis of the costs and benefits of the Clean Air Act and is expected to issue its report to Congress in 1996.

Information Needs

This chapter necessarily has relied on data developed to meet the needs of current environmental policies to describe the environmental effects of transportation. For the most part, the current environmental management system continues to treat each kind of pollution separately, even though there are complex interactions among different media. Similarly, most analyses of transportation's environmental impacts focus on individual modes—motor vehicles, aircraft, rails—rather than comparative environmental performance among modes (see box 7-4). Moreover, a complete analysis of the environmental impacts of transportation would need to take into account upstream activities (e.g., oil field development, petroleum refining, vehicle production) that make transportation possible. In conducting such analyses, special care to avoid double counting of impacts would be needed.

As policies for management of the environmental impacts of transportation evolve, so too will information needs. Questions about the costs relative to the benefits of further environmental improvement are increasingly raised, as are concerns about the dampening effects of regulation on the economy. Scientific and technical questions continue to arise concerning the nature of environmental impacts for human health and the ecosystem as a whole, and the technological capacity to address those impacts within acceptable cost-benefit ratios for society. At the same time, there is increasing interest in environmental policies that address such goals as pollution prevention and sustainable development.

Box 7-4: Comparing the Air Pollution Impacts of Different Transportation Modes

Two recent studies in California attempted to compare the air pollution emissions of two different transportation modes. One compares the emissions of truck and rail freight transportation. The other compares emissions from automobile and rail commuting. The results show that rail transportation overall produces less air pollution than motor vehicle transportation, but on a pollutant by pollutant basis the picture is more mixed.

The comparison of truck with rail freight transportation examined emissions of carbon monoxide (CO), hydrocarbon (HC), particulate matter (PM), and nitrogen oxides (NO_x) in California's I-40 corridor. (Barth and Tadi 1996). According to the study, trucks produced 2.6 times the amount of CO, 4.2 times the amount of HC, and 32.5 times the amount of PM to move the same amount of goods as rail freight. Rail produced 1.2 times the amount of NO_X as trucks, however.

The automobile/rail study compares commuting by single-occupant automobile with a rail-based commute (including getting to the train station, whether by automobile, bus, or other means) from Riverdale to downtown Los Angeles. Again, the study results are mixed. At current ridership levels (approximately 300 to 400 passengers a day), the automobile commute contributes 2.5 times more CO and 2.3 times the amount of HC than the train-based commute. The train-based commute contributes 4.7 times more NO_x and 5.5 times the amount of PM than commuting by automobile. The authors calculate that train ridership would have to reach about 2,000 passengers a day to break even on the emission of particulates and between 1,500 to 2,200 passengers to break even on NO_x emissions.

SOURCES: M. Barth and R. Tadi, "An Emissions Comparison Between Truck and Rail: A Case Study of the California I-40," presented at the 75th Annual Transportation Board Meeting, Washington DC, January 1996; and M. Barth et al., "An Emissions Analysis of Southern California's Metrolink Commuter Rail," presented at the 75th Annual Transportation Board Meeting, Washington, DC, January 1996.

Developing the information needed for such broader analyses will require a common metric for comparing different environmental effects. Many disciplines—economics, environmental science, risk analysis, and medical research, for example—would need to work together to translate environmental impacts into dollar values.

As part of a larger effort to understand and estimate the full costs and benefits of transportation, researchers are working on data and methods for costing out transportation's environmental impacts. Still, many conceptual, methodological, and statistical problems must be overcome before transportation's full costs and benefits can be understood quantitatively. Appendix B describes proceedings of a conference on this topic that BTS sponsored in July 1995. The conference addressed theoretical, methodological, and statistical issues. It also brought to the discussion of the full costs of transportation a recognition of the equal importance of transportation's full benefits.

Over the last three decades the United States has primarily applied a technology-based strategy to address the environmental impacts of transportation. So far, that approach has worked well in several areas. In the race between impact mitigation technology and demand for more transportation, however, the future is uncertain. As travel and traffic continue to grow, it becomes increasingly important to understand and monitor the relationships between transportation and the environment.

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